INJURIES
OF THE
SPINAL CORD

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Edited by

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and

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Military Personnel of United States Forces who during World War II received injury of the spinal cord

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PREFACE

Spinal cord injuries present interesting but difficult problems in many branches of medicine and surgery The experience gained from the relatively small number of cases over a period of years in civilian life has recently been greatly augmented by the large number of cases during the recent war The care of large groups of patients in Army general hospitals has offered a unique opportunity for the cooperation of specialists improvement of techniques and evaluation of methods It has also led to improved results both in reducing mortality and in furthering the extent of rehabilitation

This book brings together scattered findings in the many aspects of spinal cord injuries and records in some detail the experiences in United States Army general hospitals For convenience the book has been divided into sections each of which concerns a special field Each section synthesizes recent findings and includes some new material A specific program of treatment has been suggested whenever possible

All the contributors to this volume were actively engaged in the care of patients with spinal cord injuries during the war and have made contributions in their respective fields All acknowledge the invaluable aid of the many devoted nurses WACs and corpsmen who contributed so much skill and patience to the life and welfare of each soldier under their care Without their help the new data assembled here would not have been possible

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CONTENTS

As a result of the methods of treatment developed during the past few years the prospects for patients with spinal cord injuries have been greatly improved Most patients can expect eventually to live a comfortable social and productive life.

This book is prepared for the express purpose of providing for the student and physician in one volume the information gained by the various authors from a wide experience with the management of such patients in the Military Service as well as from their experiences in civilian life.

It is intended that this volume shall be concise and an easy reference and for this reason no attempt is made to expend space in lengthy reference to other writers excepting where differences of opinion prevail or revolutionary contributions have been made Those writers whose experiences and writings we have drawn upon will be acknowledged in the bibliography at the end of each section.

Prior to completion of certain portions of the text the authors of two chapters namely Dr R. Nelson Hatt and Dr Douglas A Thom, died It is with deep regret that the loss of these leaders in their field is reported

G C.P
F H.M

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INJURIES
OF THE
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CHAPTER IX

Chapter I

HISTORICAL NOTE

WILLIAM G KUHN JR MD

In Courville's (1) excellent historical summary we first find mention of the spinal cord about 400 B C by Hippocrates Celus in the 1st Century A.D and Aretaeus in the 2nd Century A D also made references to functions of the spinal cord The earliest known reference to *traumatic* lesions of the spinal cord is found in the Edwin Smith (2) surgical papyrus in which six cases of injury to the cervical spine were described The characteristic dislocation displacement and crushing of the vertebrae were presented In addition to the gross lesion of the spine itself paralysis of all four extremities urinary incontinence priapism and involuntary ejaculation of semen were also described Beyond this unusual surgical document nothing of note regarding injuries to the spinal cord is recorded until Galen 1st Century A.D conducted experiments on the effects of trauma to the spinal cord He found for example that a longitudinal slit in the cord failed to disturb function to any serious degree while transverse section of the cord at various levels produced paralysis of the area below the segment The significance of this work of Galen seemed lost on medieval surgeons who believed the spinal cord was comparable to the marrow of any other long bone Operations for fractures of the spine were first advised by Paulus Aegineta in the 7th Century but

close of World War I and World War II it is of the utmost importance for those future victims of transverse myelitis either due to war or to peace time accidents that every effort be made to erase the ancient and medieval concepts prevalent even today that these cases are hopeless and helpless (5)

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this suggestion was ignored until several hundred years later when Frabicius Hildanus in 1545 again referred to the advisibility of surgery in such cases However M Louis (1774) actually undertook the first operation for this condition It is of historical interest that the surgeons of this period were much more concerned with the bony lesion than they were with any injury of the spinal cord or of its various nerve roots

The matter of gunshot wounds of the spine and spinal cord was brought to light during the American Civil War In the *Medical and Surgical History of the War of the Rebellion*, are found reports of 642 such cases of gunshot wounds or 0 25 per cent of the total number of wounds recorded in these volumes The approximate percentage of such spinal cord injuries in World War II was 0 234 per cent (4)

War is without doubt the largest single contributing factor to the study of injuries of the spinal cord The studies of Frazier and Allen (3) in 1918 which were summed up in the monograph *Surgery of the Spine and Spinal Cord*, give a good general survey of the effects of spinal cord injury However their work was limited to a much smaller number of cases that survived transportation to this country from Europe, than have been returned to this country from all parts of the globe following cessation of hostilities in World War II Of approximately 20 per cent of all spinal cord injury cases that were evacuated to this continent successfully after World War I only 10 per cent of these survived the first year It is estimated that there is less than 1 per cent now living of the group on which studies were made Since modern advances in Medicine and in transportation have been so great in the years intervening between the

the early hours after injury with the result that the general health is so impaired that recovery of cord function or rehabilitation is greatly delayed or impossible

The excellent results obtained by Munro (29) in the care of patients with spinal cord injuries at the Boston City Hospital prior to World War II gave tremendous stimulus to military surgeons It was soon demonstrated that proper care of the neural injury need not in any way interfere with good nursing care attention to the urinary tract and general nutrition and also that prompt and vigorous attention to all these factors from the outset was necessary to promote the maximum opportunity for life and recovery or rehabilitation

CLASSIFICATION OF INJURIES

Injuries to the spinal cord may be roughly classified as (a) Open and (b) Closed

Open injuries, which are common in war resulting from bullets and shell fragments introduce the danger of infection, hemorrhage and the phenomena of concussion but do not often destroy the stability of the bony spine Hence though they often require open operation for the control of hemorrhage for the most part they do not require additional support with cast or brace either in the acute or convalescent stages Open injuries due to stab wounds are prone to produce partial lesions of the cord Injuries to the spinal cord due to the concussive effect of high speed projectiles may be spread over many segments

Closed injuries may result from any force that can induce fracture or fracture dislocation of the bony column These are common with highway and industrial accidents in sports particularly diving and work in mines Since the wound is closed, there is no danger of intraspinal infec

Chapter II

NEUROSURGICAL ASPECTS

FRANK H. MAYFIELD M.D

INTRODUCTION

The primary objective in management of patients with spinal cord injuries is to restore cord function to normal Unfortunately this is often unattainable, for the spinal cord, once destroyed, has no power of regeneration.* Hence, in many cases permanent partial or complete paralysis is un avoidable In the latter event every effort must be made to preserve in the best possible state all unparalyzed muscles in order that the patient may become self sustaining even though his activity be limited to the use of crutches or braces or even to a wheel chair

It is often impossible to determine at the outset whether there is a possibility of recovery for the clinical findings due to contusion or concussion may be identical with those of transection It is essential therefore that great caution be exercised in handling patients with spinal injuries to avoid additional trauma to the cord Overemphasis of danger on this score however often has led to neglect in the care of the skin, the urinary tract, and the general nutrition during

* Pyromen as recommended by Windel has been under investigation by the author for [illegible] months, but no evidence of regeneration of the cord is as yet demonstrated.

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tion and hemorrhage of surgical significance rarely if ever occurs On the other hand, the structural support of the spinal column is greatly weakened, thereby entailing the necessity of caution in handling lest additional cord injury be created, and also requiring the use of supporting casts and braces before the patient can be ambulatory In many instances the bony deformity may be sufficient to cause compression of the spinal cord If this compression is of sufficient degree to cause progressive damage or to prevent recovery it must be corrected by manipulative reduction of the deformity or by surgical decompression The trauma to the cord with closed injury is usually confined to the site of fracture

With these exceptions the problems of management are similar whether the lesion be open or closed in the early as well as the late stages

The neurosurgical aspects of spinal cord injury may be properly divided into two phases (a) Early and (b) Late

During the early phase the neurosurgeon s efforts are directed towards the promotion of recovery of cord function If these efforts fail he may be called upon in the late stages to control pain or disabling motor spasms that inhibit rehabilitation In the interests of clarity the discussion of the early phase will be considered under the headings (1) Methods of Examination, and, (2) Treatment, whereas in reference to the late phase the diagnosis and treatment of each problem will be discussed jointly

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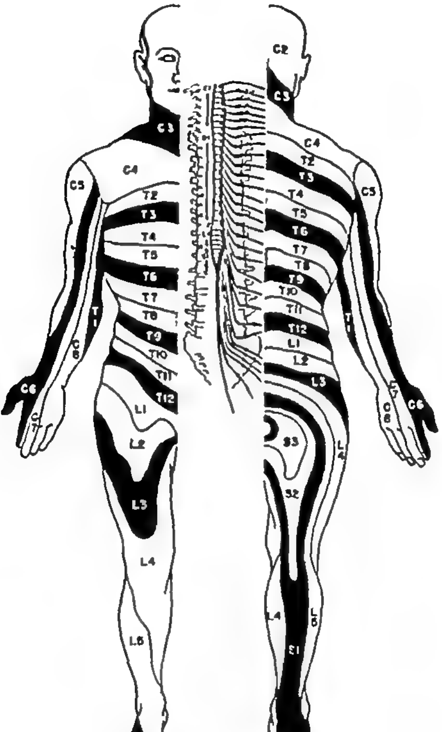
FIG. 1 Diagramatic representation of the sensory dermatomes, front and back, and also the relative position of the spinal cord and vertebral column No doubt cervical dermatomes 5 6 7 and 8 and dorsal dermatome 1 carry some sensation to the shoulder and anterior chest, but their principal function is in the arms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ANATOMY AND PHYSIOLOGY

It is not within the scope of this volume to review entirely the subject of anatomy and physiology of the spinal cord. It appears necessary however, to point out certain features of these subjects which appear to confuse the physician not trained in neurology

The spinal cord is a segmented structure (Fig 1) and in the embryo fills the entire canal but, in the process of development, the bony skeleton lengthens more rapidly than the cord, so that, in the adult, the lower end of the spinal cord is usually opposite the interspace between the first and second lumbar vertebrae Accordingly the spinal dermatomes do not correspond to the equivalent vertebrae though the roots do The clinical importance of this is obvious An injury to the spinal column at the tenth dorsal vertebra, for example will affect the cord at D-12 etc. About the trunk the dermatomes conform generally to the segments However, the lower four cervical and the first dorsal segments, for the most part, subserve the arm with the result that the fourth cervical dermatome almost adjoins the second dorsal dermatome about the trunk In a similar manner the lumbar and upper sacral segments supply the legs (See urological aspects for supply to bladder)

The lower end of the spinal canal is occupied by the roots of the cauda equina which are essentially peripheral nerves These structures are remarkably flexible and they by no means fill the bony canal Hence significant bony deformities at times produce little evidence of nerve injury Furthermore the anterior roots of the cauda equina are capable of regeneration as are peripheral nerves and hence lend themselves occasionally to surgical repair Lesions of the cauda equina induce flaccid paralysis and loss of tendon reflexes (lower

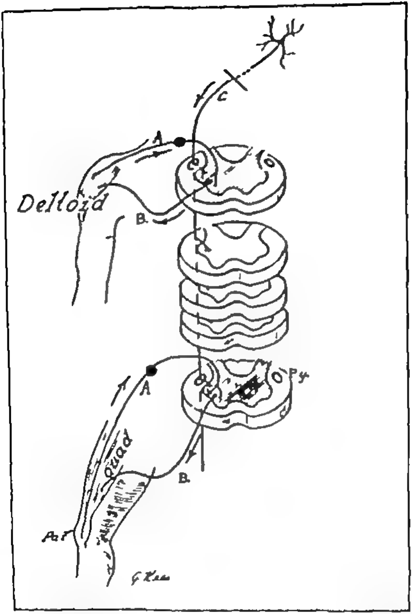

FIG 2 Diagram illustrating the basic reflex arc of the arm and leg and its relationship to the pyramidal tract (motor)

motor neuron) for the basic reflex arc is broken (Fig 2) In contrast, when the spinal cord itself is injured spastic paralysis follows with hyperactive reflexes for the basic reflex arc is usually intact below the site of injury

Every cord injury at any level will create a combination of upper and lower motor neuron lesions by destroying the reflex arc at the site of injury but leaving that portion below the injury intact Through the thoracic area the lower motor neuron phenomena, due to the destruction of one or two segments is not clinically recognizable but in the region of the conus medullaris or the cervical bulb where many segments are compressed into a short area, it is possible to demonstrate at times evidence of flaccidity of the muscles in certain segments with spastic phenomena present below (Fig 3) Allen (1) has demonstrated that the area of cord contusion following compression from fracture dislocation is distributed as a double inverted cone and may spread over

FIG 3 Photograph of a patient with fracture dislocation of C 5 on C 6, with complete transection of the cord. Note the bilateral wrist drop (flaccid) This patient subsequently developed massed reflexes in the lower extremities

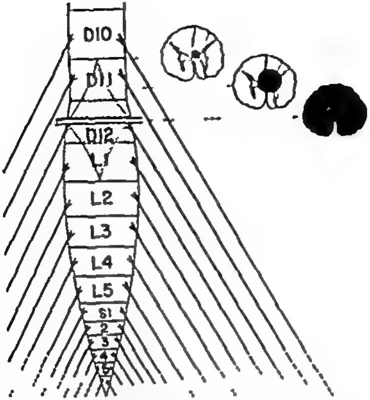

FIG. 4 Diagramatic representation of cord compression showing segmental destruction with transection Note the inverted double cone described by Allen (Redrawn from Cohen and Lambert War Injuries of the Spine and Cord Surgery of Modern Warfare, Third Edition Volume II Bailey Williams and Wilkins Baltimore 1944)

an area of three or four segments Gunshot wounds of course may produce much more extensive damage (Fig 4)

One would anticipate that clinical signs of an upper motor neuron lesion would appear simultaneously with the injury However due to a poorly understood phenomenon generally spoken of as spinal shock the paralysis may be flaccid and all reflexes completely absent for several days or weeks even after complete transection of the cord (see massed reflexes)

EXAMINATION

If consciousness is retained the patient with a severe spinal cord injury is instantly aware of motor and sensory paralysis below the level of injury and usually volunteers the information that the legs cannot be moved and are numb and complains of pain at the site of injury This information should lead the first observer to exercise great caution in handling the patient At times however due to altered state of consciousness from a coincidental head injury or the con fusion and excitement that accompanies shock, the patient may not be aware of his state Under these circumstances the examiner can usually determine by painful stimuli, such as a pinch or pin prick, if sensation and/or motion is lost. Having made the determination that cord injury exists and proper precautions for transport arranged additional ex amination may be deferred until the patient has reached the hospital where after any existing shock is controlled, a complete examination may be undertaken

The examiner s objectives include the location of the lesion, its extent as reflected by loss of function whether it is progressive, static or improving

Complete physiological section of the cord will abolish all sensation and motion below the level of injury For variable periods the paralysis will be flaccid in type and all reflexes absent for several days or weeks There will be loss of sweat over the anesthetic area and retention of urine If the lesion is high there may be marked abdominal distention due to a paralytic ileus This may last for several days With lesions in the cervical area respirations are labored due to loss of the accessory respiratory muscles There is often a fall of blood pressure resulting from the

loss of sympathetic pressor tone to the peripheral blood ves-sels With injury to the cervical cord the temperature may rise presumably as the result of ascending edema that has reached the heat regulating mechanism of the brain and this is often a morbid sign

Careful record of the initial sensory, motor and reflex deficit and any other finding should be made for comparison with future findings for treatment is dependent upon the patient s clinical course (Fig 5)

The reader is referred to any of the many good texts in neurology as a guide in methods of neurological examination In general it may be stated that the determination of sensory loss is a more precise method of localizing the neural lesion than motor or sympathetic changes It is well to point out however certain signs which are dependent upon alterations of motor and sympathetic function that aid in localization Paralysis of the shoulder muscles for instance places the lesion in the upper cervical area. Paralysis of the muscles of the hand with escape of the shoulder muscles places the lesion in the lower cervical area The latter is often asso-ciated with a Horner s syndrome particularly if the lesion in-volves the eighth cervical or the first dorsal segments Pri-apism occurs with cervical and upper dorsal lesions generally this is not constant, however Retractions of the umbilicus upward with respirations indicate a low dorsal lesion etc.

Analysis of the reflexes constitutes a most important diag-nostic step Due to spinal shock all tendon reflexes are absent immediately after a cord injury particularly if the injury is complete On the other hand a flexion plantar response is usually elicited on stroking the sole of the foot The writer has regarded this finding as evidence of complete cord section if observed during the first few hours after in-

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jury whereas a plantar reversal (Babinski Oppenheim Gordon etc) is thought to indicate a more favorable prognosis The same would be true of a tendon jerk For example if examination immediately after a cord injury shows all tendon reflexes and pyramidal tract signs below the level of injury to be absent along with loss of motor and sensory function it is probable that the lesion is complete On the other hand if one can elicit a knee jerk ankle jerk or a Babinski sign it is probable that a substantial portion of the cord is structurally intact and capable of recovery

With the passage of spinal shock which may extend as long as several weeks peculiar phenomena begin to appear in the muscles below the lesion principally in the legs and may progress to a state of extreme muscle tone in which massed reflexes are set off by stimuli anywhere in the anesthetic zone The onset and course of development of these changes is very variable and inconsistent Indeed it varies greatly in different cases and in degree in the same case particularly when influenced by systemic infection (see motor spasms and massed reflexes) As this begins it may be mistaken for recovery and hence must be interpreted guardedly Some have interpreted these findings as indicative of a complete lesion and in many instances it does develop when the lesion of the cord is complete On the other hand it does occur at times when the lesion is incomplete

Most patients who show these clinical findings never improve for the cord cannot regenerate Some (33) believe that an incomplete lesion always can be recognized clinically but the writer has observed several cases of cord injury due to bullet wounds which appeared complete to astute and experienced examiners who subsequently showed recovery and

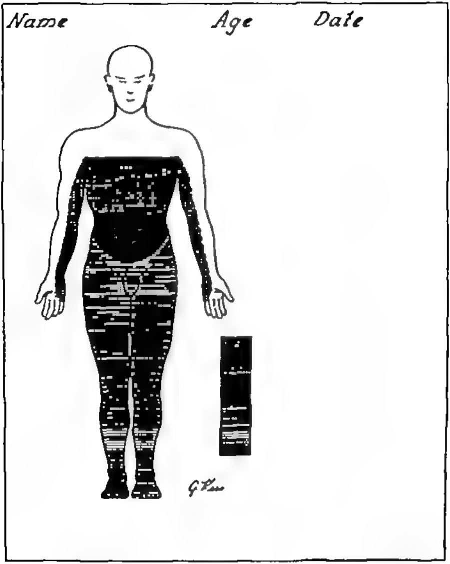

FIG. 5 Sensory record of a patient with injury involving the first dorsal dermatome Note various types of shading to indicate modalities involved This record should be completed on every patient when he is first seen and repeated at frequent intervals thereafter

FIG. 6a. Fracture dislocation of the spine with complete cord lesion Note the shearing force of the lesion with fracture of the tenth rib on the left side and the eleventh rib on the right Fracture caused by a tractor falling on the patient

also several patients with closed injuries that were interpreted as complete have gone on to excellent recovery

While it is recognized that cases that show findings of complete physiological block offer a poor prognosis never theless they should be treated on the assumption of possible recovery

Incomplete Lesions The lesion of the cord may be regarded as incomplete when any evidence of function is preserved below the level of injury The perception of sensation even though it may be confined to deep pressure may be regarded as a hopeful sign A positive Babinski or a retained tendon reflex during the first few hours after injury is indicative of a partial lesion and with closed injuries offers a fairly favorable prognosis There are certain peculiar and misleading neural patterns, particularly in the sensory field, that may confuse an inexperienced examiner For instance, testicular sensation is received through the twelfth dorsal dermatome whereas scrotal sensation is derived from the sacral segments Hence pain on pressure of the testicle when the lesion is below the twelfth dorsal dermatome does not indicate that the lesion is partial

Having determined that the lesion is incomplete a discriminating neurological record should be made and checked frequently by repeated examinations for the election of treatment and the prognosis are dependent in large measure upon the progress either for better or worse that takes place

X RAY EXAMINATION

Thorough x ray examination of the spine is an essential procedure and can be accomplished safely in most instances Fractures may be shown fracture-dislocations visualized, foreign bodies localized and bone healing recorded (Fig 6)

Rarely however does the picture record the maximum deformity that has occurred with closed injuries for as a result of recoil the bony deformity is reduced in many instances

The examiner should be aware of certain pitfalls in reference to x ray examination For example in x ray study of the cervical spine it is necessary to include open mouth views to

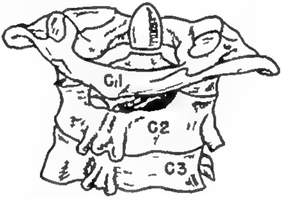

FIG. 7 Drawing of fracture of the odontoid Open mouth view required to visualize in x ray

show the odontoid and the atlanto-axial joints (Fig 7) Fractures of the lower cervical spine may be overlooked unless the exposure is made while the shoulders are being pulled down and traction is being maintained on the head With compression fracture of the upper lumbar vertebrae, pain is often referred to the sacrum (McKeever) Coleman and Meredith (11) state that with combined head and shoulder injury fractures of the cervical spine are so common that this part should always be x rayed even though there are no symptoms referable to it

The localization of foreign bodies should be checked just prior to operation for if they are within the canal they may move with change of position (Figs 8a 8b)

Fig 6b Gunshot wound showing bullet imbedded in spinal canal.

Fig 8b X ray of 8a three days later indicating that the fragment has shifted in the spinal canal Note that it is several segments lower

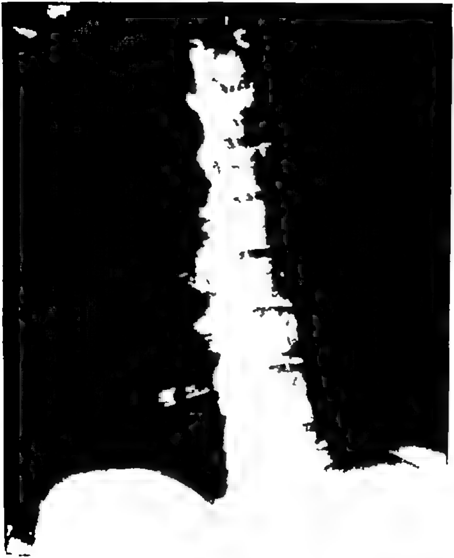

FIG. 8a. X ray of gunshot wound showing path of bullet and bullet imbedded in the spinal canal.

tient who comes in with evidence of cord injury and whose course is one of improvement spinal puncture is not indicated With penetrating wounds, while the clinical level is specific and the indications for operation clear-cut, hence spinal puncture is not necessary, but in those patients where paralysis is severe or where it has been minimal in the beginning and has been growing worse valuable information is gained from this test

Queckenstedt Test Normally the fluid column in the spinal canal is continuous with that of the cranial cavity Hence when the intracranial pressure is raised the spinal fluid pressure is also increased The intracranial tension can be raised at will by jugular compression Failure of the spinal fluid pressure to rise simultaneously would indicate that the normal channel connecting the two spaces is obstructed The Queckenstedt test utilizes this principle to determine if the spinal cord is compressed To perform the test, a lumbar puncture is done in the usual manner The initial spinal pressure is recorded It is then necessary to insure that the puncture is satisfactory by having the patient cough or strain or by pressing on the abdomen while the manometer is still atttached to the needle These acts raise the intra abdominal pressure engorging the communicating lumbar veins with the result that the spinal fluid pressure is raised slightly perhaps 20 to 50 mm of water It quickly returns to its former level when the intra abdominal pressure is lowered There is a slight alteration with pulse and respirations also When bilateral jugular compression is applied either digitally or by inflated cuff (Fig 10) the spinal fluid pressure will in the normal begin to rise almost immediately and may increase by 200 to 400 mm within five seconds It will return to its former level within five to

LUMBAR PUNCTURE

Information relative to bleeding infection and the cerebro-spinal fluid dynamics may be gained by lumbar puncture Bleeding of significant degree is not common with closed spinal injuries Penetrating wounds however introduce the danger of hemorrhage and secondary infection

The normal spinal fluid pressure ranges from 100 to 200 mm of water and the fluid is clear and colorless

The puncture is performed more easily in the lateral recumbent position (Fig 9) but it may be performed in the face-down position in certain circumstances In patients with spinal cord injury the sitting position never should be used In the paraplegic patient no anesthetic is required, but otherwise local infiltration with procaine is necessary

The indications for spinal puncture however are dependent upon the patient s progress In the case of the pa

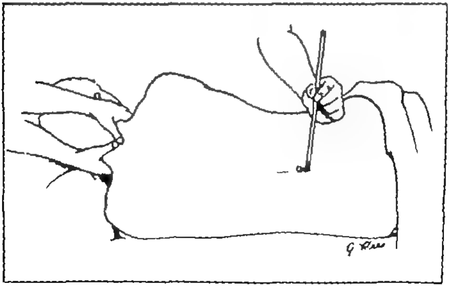

FIG 9 Spinal puncture needle in place with manometer attached and jugular compression being applied.

FIG. 11a. Old compression fracture, showing angulation in a patient who developed gradual progressive paralysis over a period of eight years following an injury

in most clinics to interpret the test as showing no block, a partial block or a complete block

While the test does not localize the point of compression, it is an extremely valuable procedure and should be carried out on all patients with spinal cord injury It is advisable that it be performed soon after the injury as a baseline for determining progress if the patient fails to show clinical improvement or grows worse Coleman (12) has long considered this a valuable procedure The writer with Cazan

ten seconds after release of jugular compression (Fig 10) if the spinal canal is patent

If the canal is obstructed the spinal fluid pressure is not affected by jugular compression (Fig 10)

If the lumen of the canal is reduced below the diameter of the needle used but not completely obstructed [Poppen and Hurxthal (35)] the rise of the spinal fluid pressure may be delayed several seconds after jugular compression is applied and then rise slowly but will not reach levels as high as the normal After release of jugular compression the spinal fluid fall is slow and may not seek the original low level (Fig 10)

Queckenstedt originally proposed that the normal response be labelled a positive test and the abnormal a negative test. This is confusing however and it is not customary

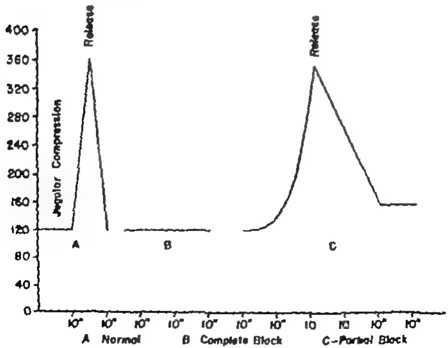

FIG. 10 Graphic representation of response to jugular compression

the normal This may be true Usually however, ulceration of the skin is an expression of neglect If the position is changed regularly at two or three hour intervals and care exercised to protect bony points ulceration will never occur provided urinary sepsis is avoided and nutrition maintained Rubber rings and gauze rings afford little protection and usually give the nurse a false sense of security Standard

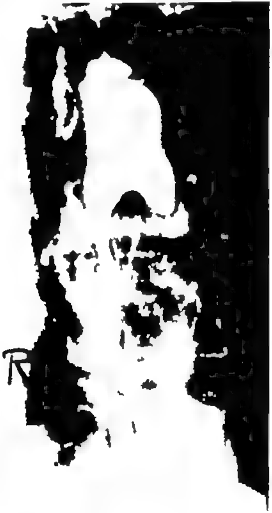

FIG 11b Myelogram, showing almost complete block at site of angulation

(26) showed however, that obstruction of the canal was not incompatible with functional recovery and accordingly not a fixed indication for surgery

MYELOGRAPHY

Visualization of the spinal subarachnoid space with contrast media is not often necessary after spinal cord injury The level of the lesion can usually be determined by x rays of the bony injury and the neural deficit, and the presence of compression may be determined by the Queckenstedt test. Myelography is indicated at times, however particularly with partial cord lesions or lesions that show late progression (Figs. 11a, 11b)

TREATMENT

Theoretically fractures of the dorsal and lumbar spine should be transported face-down and cervical fractures face-up However it is so rare for those who discover the victims to be capable of this diagnosis it is advisable that they be transported with the least manipulation of the back possible and face up with the head supported between sandbags, with precautions exercised to insure an adequate air way If the trip is to involve many hours, precautions should be taken to prevent decubiti for the necrosis which leads to decubiti may occur within three or four hours

Transportation about the hospital should be done carefully with sufficient attendants to insure that motion of the spine is minimal With one person holding the head another the legs and a third rotating the trunk, the patient may be safely turned for x rays and nursing care

It often has been stated that the skin of the paraplegic is more vulnerable to trauma and hence to ulceration than

paralysis even though portions of the cord are preserved and capable of recovery It must be presumed that the effect of concussion is capable of masking signs of bleeding and compression from foreign bodies and/or infection and hence it is wise to explore and correct any such changes as may lead to additional damage even though the injury of the cord appears to be complete

It is in connection with closed injuries that there is wide difference of opinion concerning the indications for laminectomy Some contend that decompressive laminectomy should be done in all cases Others are equally committed to the philosophy that decompressive laminectomy in closed injuries is never indicated The writer rarely finds it necessary to perform a laminectomy but under two circumstances it is done first if it can be shown that bony compression is retarding recovery in partial cord lesions and secondly in those cases where obstruction of the canal is demonstrated and x ray reveals sufficient deformity to cause cord compression and clinical findings harbor doubt as to whether the lesion is incomplete

If one can approach this question in each case with an open mind usually wiser decisions will be arrived at Rarely is there indication for laminectomy as an emergency procedure in the patient with an acute closed injury In general one can assume that the greatest deformity of the spine occurs at the moment of impact and that the changes noted subsequently in x ray are after the recoil has produced partial reduction This deformity still may be sufficient to prevent recovery The compression may be the result of displacement of one vertebra on another or the result of an indriven fragment of bone, but no method of examination with which I am familiar will enable one to decide immedi

hospital mattresses supported by boards are adequate. Special air or rubber mattresses are not needed Treatment of these decubiti when formed will be covered in another section

EARLY MANAGEMENT OF SPINAL INJURY

With penetrating wounds, stability of the spinal column is usually maintained Therefore transportation operative correction and early calisthenics if required, often may be undertaken without supporting casts or braces

Fracture or fracture dislocation must be immobilized either with supportive splints or traction The period of immobilization varies depending upon the extent of the fracture but usually entails immobilization in a horizontal position for at least six weeks before the patient is allowed to sit up with cast or brace Cervical fractures are treated with skeletal traction from the outset. Dorsal and lumbar compression without cord injury are immediately reduced by hyperextension and immobilized in a plaster cast. When these injuries are associated with cord injury, it is preferable not to use encasement plasters from the outset, as it inhibits the close neurological observation that is so important However once the issue of operation upon the spine is eliminated the patient is placed in plaster and started upon a vigorous exercise program (see orthopedic section)

INDICATIONS FOR LAMINECTOMY

It is generally agreed that exploratory laminectomy is indicated in all patients with penetrating wounds of the spine Matson (25) drawing upon his own experience and that of other military surgeons in World War II has documented this premise well This stand appears justified since the concussion effect of the projectile often induces complete

paralysis after admission should have the lamina at the site of injury removed Patients with fracture dislocations who fail to recover adequately should have the fracture dislocation corrected (Fig 12) usually by open operation On the other hand the presence of an x ray deformity does not in itself warrant laminectomy (Fig 13) Remarkable degrees of dislocation can occur without injury to the cord when the laminae of the superior fragment become detached from the body Bony healing in this position often occurs without any sign of cord injury at all

On the other hand certain patients with a fracture or fracture-dislocation will show progressive paralysis when they become ambulatory as the result of gradual displacement of fragments In this instance decompressive laminectomy and/or spinal fusion may be in order (Fig 14)

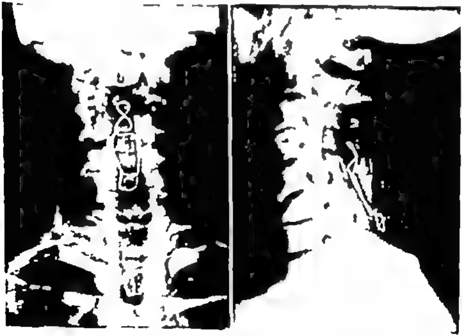

FIG 12b Paralysis relieved after partial reduction with removal of lamina and articular facets and bone graft

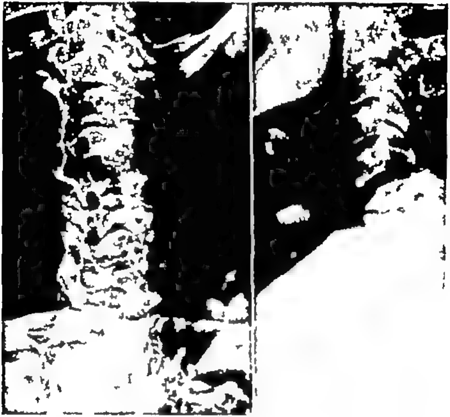

FIG 12a Fracture dislocation of C 5 on C-6 uncorrected by skeletal traction. No paralysis until patient became ambulatory when rapid onset of weakness in the legs with pain in the arms developed

ately that correction of the bony deformity is necessary As a rule no harm will accrue to the patient as the result of delay for a few hours or a day or two The presence of blood in the spinal canal or an obstruction as shown by the Queckenstedt test are not adequate indications The distress of grieving relatives and friends also is not considered an adequate indication for operation A patient who has an in driven fragment of bone either of lamina or an articular facet, and who fails to recover should have that depressed fragment of bone removed A patient who shows progressive

FIG. 14a. Compression fracture of the first lumbar verterba with displacement of the posterior half of the body Paralysis minimal until the patient became ambulatory

Cervical Injuries—Skeletal Traction Fracture and fracture-dislocation of the cervical spine are most satisfactorily treated by skeletal traction applied to the skull The writer has had no occasion to do a laminectomy on a cervical injury since the introduction of the Crutchfield tongs method of traction (Fig 15) The tongs are simply and easily applied They are centered over the vertex in line with the mastoid processes A special drill point creates an opening

FIG. 13 Dislocation cervical spine C 5 on C 6 after traction with Crutchfield tongs for four days with 15 lb weight. Dislocation not reduced due to interlocking facets Note widening of intervertebral spaces and straight spinal axis Excessive stretching may produce brachial plexus symptoms

sirable but not necessary The structure of the tongs permit the patient to be fed and turned while traction is still applied and the patient is quite comfortable

Inexperienced surgeons complain of difficulty maintaining the tongs in place In this clinic, traction is often maintained for four to six weeks Only one skull infection has been encountered

Recently Vinke (41) has developed a new tong (Fig 16) The inventor claims that the locking device beneath the outer table prevents slipping either out or in Thompson has

FIG 15 Crutchfield tongs in place

FIG. 14b Paralysis corrected after decompression and spinal fusion

through a stab wound of the scalp The tongs then are fixed in place with setscrews and traction applied with 20 to 25 pounds over a single pulley Reduction of the dislocation may occur within a few minutes to a few hours The weight is then reduced Occasionally complete reduction does not occur (Fig 13) but a moderate degree of dislocation is compatible with spinal stability Perfect reduction is de-

sirable but not necessary The structure of the tongs permit the patient to be fed and turned while traction is still applied and the patient is quite comfortable

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FIG 15 Crutchfield tongs in place

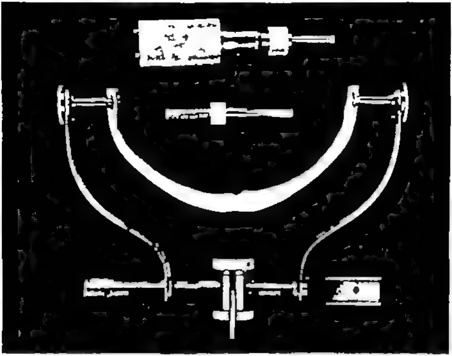


FIG. 16 Vinke tongs for skull traction. Note the locking devise between the inner and outer tables (safety measure)

developed hooks that apply under the zygoma Hoen has placed wires through the skull To this observer either of these techniques is satisfactory though the wires through the skull incur certain risks that prohibit its use by one not skilled in neurological surgery

Bony injuries in the dorsal and upper lumbar area are not correctible by skeletal traction Hence where compression of the cord of sufficient degree to require decompression is present laminectomy with manipulative reduction of the dislocation is the procedure of choice When operating upon cases of this sort, the possibility of a ruptured intervertebral disc in addition to the fracture must be recognized. Certain of the deformities can be corrected by hyperextension, and in prop-

erly selected cases this method of treatment should be tried prior to operation

TECHNIQUE OF LAMINECTOMY

The patient is placed on the table face down usually on a cerebellar rest The latter is essential if cervical laminec

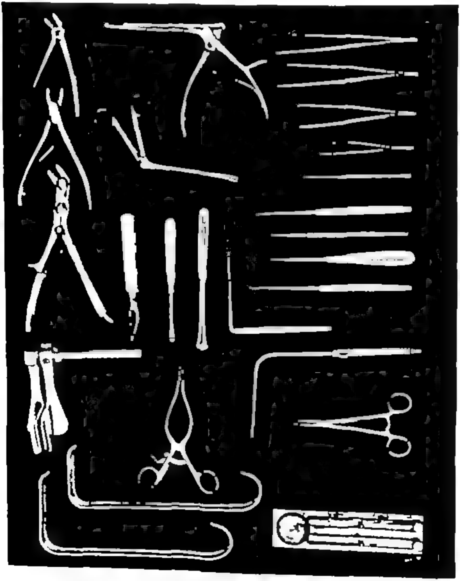


FIG. 17 Special instruments used in laminectomy

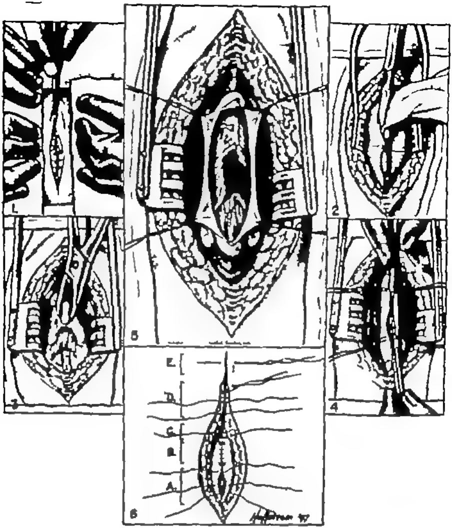


FIG. 18 Technique of laminectomy showing cord lesion.

tomy is to be done Anesthesia may be local or general Figure 18 reveals the special instruments required for laminectomy Figure 17 shows the steps of exposure

When operation is done for a penetrating wound the path of entry should be debrided if in the field and the bony arches removed with great caution lest the rongeurs displace

bone or metal within thereby inflicting additional trauma All bone metal, clot and debris should be removed Often times penetrating fragments will come to rest in the spinal canal and induce severe cord damage without penetrating the dura Nevertheless the dura should be opened unless the field is infected Unless infection is present, tight closure of the dura muscle and skin should be done

When the laminectomy is done for closed injuries one should exercise great caution in dissecting the muscles and removing the laminae lest the unstable joint be manipulated thereby creating additional injury It is better to open normal tissue first, approaching the injury site after exposing a normal lamina above and below

If operation is done within the first few hours after injury the cord may look surprisingly good even though the paralysis appears complete Actually the pia is rarely torn and so maintains the cord in grossly normal contour even though it is completely disintegrated Palpation will usually reveal the softened segment If operation is done late one may find the proximal and distal end joined by filmy scar tissue.

The postoperative care of cervical laminectomy should include the continued use of skeletal traction

After dorsal or lumbar laminectomy for fracture dislocation immobilization in a hyperextension cast is necessary

CONTROL OF PAIN

The severe pain that goes with acute injuries is not a surgical problem Instead it is properly treated by immobilization and analgesic drugs On the other hand in the later stages of management the control of pain may

become an important and trying problem The profound psychic trauma that is inflicted on the able-bodied individual who suddenly becomes paralyzed and must accept a life of permanent paralysis is profound Some never adjust, and of those who fail to adjust may complain of pain The pain varies widely, and it is at times most difficult to determine whether the symptoms are purely on a functional basis or the result of mechanical encroachment on pain pathways etc It is necessary therefore that one should not consider destructive operations for the control of pain in the paraplegic unless psychiatric investigation has been tried and found ineffective

IMMOBILIZATION

a. Pain caused by an unstable spine usually can be controlled by immobilization either by cast or brace or by fixation with bone graft.

RHIZOTOMY FOR PAIN

b In radicular pain due to retained bone or metal fragments or fibrosis about the nerve at the site of injury and if clinical findings indicate that the pain is confined to only one or two roots, removal of the retained foreign bodies or bone and section of the roots in question will provide relief (This is not to be confused with rhizotomy for massed reflexes)

SYMPATHECTOMY

c Burning pain in one leg is seen at times after penetrating wounds of the cauda equina. This may be causalgic in type and warrants a diagnostic procaine block of the lumbar sympathetic chain If relief follows lumbar sympathectomy then is justified

CHORDOTOMY

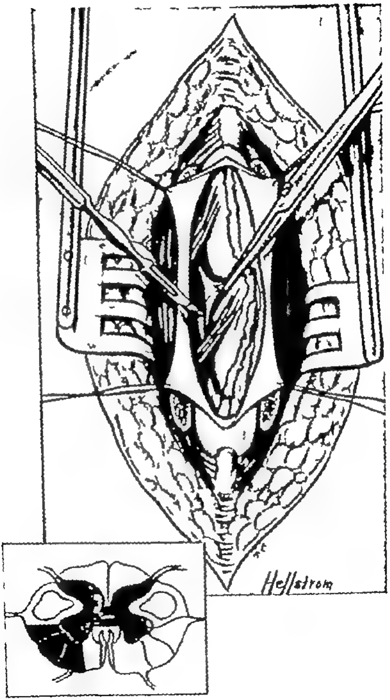
d Numerous patients with cord transection complain of intractable pain in both legs In certain instances this is hysterical and the aid of a psychiatrist should be sought before resorting to surgery If the pain still persists one is justified in sectioning the pain tracts in the spinal cord (Fig 19) This is an operation that should be undertaken only by one of considerable skill and experience

DRUGS

e The use of drugs in the control of pain is mentioned only to condemn it These patients are easily addicted to the opiates and these should be withheld except during the acute phase of the illness

CONTROL OF MOTOR SPASM (MASSED REFLEXES)

Among the most disturbing phenomena that appear in the patients with cord injury is massed reflexes or motor spasms This is more often seen with complete transection of the cord but also occurs with partial lesions After passage of the period of spinal shock the tendon jerks appear there is a withdrawal response with plantar stimulation which gradually increases in excitability and power until they are set off by any stimulus in the anesthetic zone such as stroke of the skin particularly about the genitals Attempts to turn in bed or to take foot may set off motor spasms that involve all the paralyzed muscles These precipitate forceful emptying of the bladder They keep the patient fatigued They greatly impede nursing care and limit the patient s capacity to engage in calisthenics or other forms of rehabilitation (Fig 20)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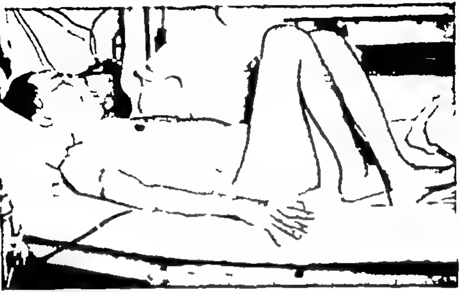

FIG. 20 Patient with complete lesion of the upper dorsal cord with painful adductor and flexor spasms

Riddoch (39) evidently considered this as a cerebral release phenomenon created by transection of the cord How ever little is actually known of the pathologic physiology It does not occur in all patients with similar lesions Furthermore with lesions at identical levels the spasms may involve different muscle groups Elkins and Wegner (18) have classified them as simple flexion, crossed extension extensor thrust reflex stepping and mass reflexes The extensor thrust they thought to occur in partial lesions only Investigations by Pool (35) and Scarf (40) led them to conclude that scar tissue in the distal end of the cord might account for the spasms by exciting the posterior columns

←
FIG 19 Technique of chordotomy A cut 4 to 5 mm., in depth is made to extend from the dentate ligament to a point 1 mm. anterior to the anterior root. It is necessary to make the section several segments above the point of pain Pain and temperature sensation is abolished on the opposite side of the body below the level of section.

Their work was interesting and painstaking but late developments in their cases defeated these arguments Whatever the causative mechanisms, the motor spasms present a disturbing problem to the patient at times and require cor rection

Munro (30) proposed bilateral section of the anterior roots from L 1 to S-1 in order to render flaccid the muscles of the legs which caused the disturbance yet would leave the reflex arc to the urinary bladder intact This has been done successfully by many surgeons though certain technical difficulties in identifying the desired roots have led to error at times Munro states that the last dentate ligament identifies the first lumbar root Botterell (5) however finds this inconsistent but points out that the first sacral root is always much larger than its adjacent root below The procedure of rhizotomy as recommended by Munro and modified by Botterell was adapted for patients with severe massed re flexes who had no chance of improvement Shelden and Pudenz (40) have controlled these spasms by the use of 95 per cent alcohol injected into the region of the cauda equina, and the writer has come to use this as the procedure of choice in the control of motor spasms The reflexes in the legs are abolished, yet automatic bladder function is not interfered with It was thought that only temporary relief would follow this procedure The writer however has one patient who was injected four years ago who still has no return of motor spasms A spinal puncture needle is passed into the second lumbar interspace with the patient in the lateral position and the buttocks elevated at an angle of 45 to 60 Five cc of absolute alcohol are then injected into the subarachnoid space and the patient turned quickly on his back and maintained in this position for at least three

or four hours The alcohol, being lighter than the cerebrospinal fluid gravitates to the caudal end of the sac and around the anterior roots The release of spasms is almost instantaneous

It is necessary to emphasize that either rhizotomy or alcohol injection are destructive and irrevocable procedures and hence should be applied only when all hope of recovery of voluntary function has been abandoned

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Chapter III

UROLOGICAL ASPECTS*

GEORGE C. PRATHER, M D

INTRODUCTION

The urological problems arising from spinal cord injury have been recognized as of major importance for many years, and experiences in the recent war have confirmed this view As the patient survives the initial impact of the injury and the immediate procedures designed to restore the maximum neurological recovery attention must be promptly directed to the urinary tract in an effort to avoid serious complications and to make possible optimum recovery of bladder function

Throughout the chapter the respected opinion of many contributors to the subject have been quoted. In the clinical phases personal opinions and observations supplement the views of others

In order to carry out a proper program of treatment a thorough understanding of the normal urinary tract and the influence of disturbed nerve supply to the various organs appears essential We first briefly review the normal anatomy and physiology of the bladder and summarize the experimental and clinical data on the urinary tract after spinal

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cord injury We then describe methods of study and forms of treatment and finally discuss the possible complications that may arise in the urogenital tract

THE BLADDER

GENERAL DESCRIPTION

The bladder is a balloon shaped organ with a distensible main portion and a small neck like outlet (internal urethral orifice) Two small openings (ureteral orifices) are located near the internal urethral orifice The triangular area formed by the two ureteral orifices and the internal urethral orifice is called the trigone and is covered by mucous membrane which is firmly attached to underlying muscle tissue The trigone therefore, remains smooth and unwrinkled in appearance even though the bladder is empty The transitional epithelium lining the main portion of the bladder is loosely attached to the muscular part of the wall by a layer of areolar tissue (submucosa) This loose attachment produces a wrinkling of the mucosa when the bladder is empty and permits a smooth surface when the bladder is distended

MUSCULAR WALL

The muscular wall of the bladder consists of three interwoven layers of non-striated muscle fibres An outer longitudinal a middle circular and an inner longitudinal layer are collectively known as the *detrusor muscle* In the caudal portion of the bladder (bladder base) the ureters with their muscular wall penetrate the bladder obliquely Their muscular portions fan out underneath the trigone the mesial portion joining a similar portion from the opposite ureter to

form the posterior (transverse) border of the trigone while the lateral portions run obliquely medialward over the bladder neck to end in the region of the prostatic urethra as described by Bell (9) *

Griffiths (59) has written an interesting historical account of early anatomical descriptions of the bladder musculature Apparently Galen was first to observe the longitudinal, transverse and oblique fibres in the bladder wall and a sphincter like mechanism at the bladder neck, but Fallopius was first to regard these fibres as muscle The term detrusor muscle was originally used by Spiegel to designate only the longitudinal fibres but Elden in 1722 used the term to include all layers of bladder muscle

Griffiths also performed careful dissections of the human bladder after distending it with methylated spirits to harden its wall He believed the trigone was composed of only the inner layer of muscular fibres being separated from the outer layer by a thin layer of fibrous tissue Griffiths found the trigone as a distinct structure only in man and some monkeys

BLADDER NECK

The exact arrangement of involuntary muscle fibres in the region of the internal urethral orifice is still obscure despite numerous anatomical studies by competent observers among whom are Griffiths (60-61) Bell (9) Young and Wesson (197) and Wesson (193) Although there is probably not a complete ring of muscular tissue at this point similar to the anal sphincter the fact that urine does not ordinarily pass beyond the bladder neck and into the urethra

* Numbers refer to bibliographic references of corresponding number

in the non voiding state implies at least the physiological existence of a sphincter mechanism

Briefly one may visualize muscle fibres from the bladder wall and trigone converging toward and surrounding the internal urethral orifice some fibres forming the posterior border of this opening while others sweep laterally and anteriorly in sling like fashion into the region of the pro tatic urethra to join in the ventral portion of this channel

Whatever the details of the anatomy of this complex region may ultimately prove to be there can be no harm in continuing to use the term internal sphincter if it is understood that the common circular arrangement of the muscle is not inferred

ATTACHMENTS

In the region of the internal urethral orifice in the male the neck of the bladder is firmly attached to the prostate, which is in turn supported by the perineal muscles Anteriorly the pubovesical ligament forms a connection between the bladder neck and pubic bone Posteriorly the rectovesical muscle is found between the base of the bladder and the rectum The vertex of the bladder is connected to the anterior abdominal wall by the remains of the urachus in the form of a fibromuscular cord known as the middle umbilical ligament Peritoneum covering the obliterated hypogastric arteries as they course from the lateral surface of the bladder toward the umbilicus forms the anterior false ligaments while peritoneal reflections from the bladder to the lateral walls of the pelvis and to the retrovesical or sacrogenital folds form the lateral and posterior false ligaments

In the female the posterior surface of the bladder is in relation to the anterior surfaces of the upper part of the vagina cervix and uterus

BLOOD VESSELS

Arteries which supply the bladder are branches from the hypogastric artery on each side of the bony pelvis. The superior vesical arteries supply branches to the dome of the bladder and branches of these vessels are sometimes called the middle vesical arteries The inferior vesical arteries are distributed to the fundus and base of the bladder and to the prostate and seminal vesicles Veins are less well defined They form a complicated plexus around the inferior surface of the bladder near the prostate and end in the hypogastric veins

NERVES

Nerves concerned with bladder physiology include sympathetic and parasympathetic fibres collectively described as the autonomic innervation, and somatic nerves that supply the external urethral sphincter In addition, pathways from these nerves to higher centers deserve consideration They are known as suprasegmental pathways

Elliott (42) in an historical review of contributions to the neuroanatomy of the bladder gives credit to Budge (21) and Giannuzi (58) for demonstrating that impulses capable of producing contraction of the bladder reached that organ either via lumbar spinal roots in the hypogastric nerve or via sacral roots in the pelvic visceral nerves

One difficulty for a complete understanding of the neuroanatomy and physiology of the bladder is the fact that it differs from animal to animal Gruber (62) has stressed the variable origin and route of efferent nerves to the bladder in different species of animals and even in animals of the same species As Elliott stated a number of years ago one cannot argue from the particular to the universal There

appears to be need of further details, particularly in man

The present conception of the nerve supply to the bladder in man is indicated in diagrammatic form in Figure 1. More detailed description of suprasegmental pathways, the autonomic and somatic nerves will now be given.

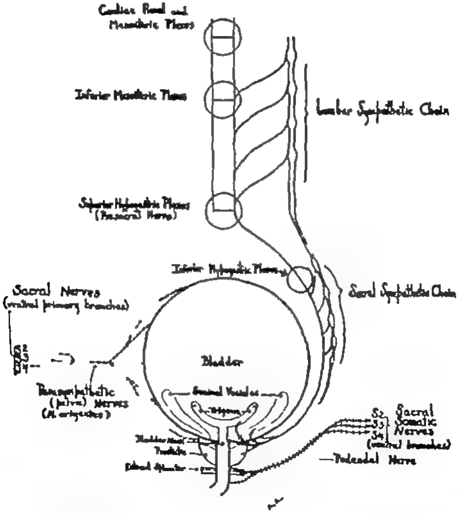

FIG 1 Diagram of nerve supply to the bladder. Although sensory fibres are found in the trunks of the sympathetic and parasympathetic nerves as well as in the pudendal nerve, all sensory nerves are considered as part of the somatic system.

Suprasegmental Pathways Voluntary control of micturition and the disturbed bladder action accompanying lesions of the cerebral cortex indicate that the lower nerve segments supplying the bladder are connected with the higher centers of the central nervous system but the exact pathways are not known

Numerous experimental studies summarized by Langworthy Kolb and Lewis (92) prove that there is a definite cortical influence on urination In cats they demonstrated that certain cortical areas when stimulated induced variable reactions which either initiated or stopped micturition After removal of cortical motor areas the bladder became sensitive to the stimulus of distention

Barrington (6) concluded that bladder tone is controlled by the region of the lower part of the mid brain and these findings were confirmed in experiments by Langworthy and Kolb (87)

Fearnsides (49) quotes experiments by Mosso and Pellacani (111) which indicated that cerebrovesical pathways run in the posterior segment of the spinal cord Investigations by Stewart (174) indicated that impulses to the bladder travel in the posterior part of the lateral columns and can cross from one side to the other in the lumbosacral region In a review of previous contributors Creevy (31) concluded that motor fibers to the bladder lie in or about the pyramidal tracts while the sensory fibres course in the posterior columns In the spinal cord of cats Barrington (7) also found paths controlling micturition situated in the dorsal half of the lateral column near the periphery and believed that the pathways undergo extensive crossing in the segments from which the pelvic nerves emerge McClellan s (106) clinical observations, however led him to believe that both the as-

cending and descending pathways affecting the bladder lie close together in the anterolateral column

Clinical observations in which lesions of the motor cortex produce a disturbance of bladder function are common Lewis (100) indicated that bladder dysfunction is more frequent after cerebral accidents which cause a right hemiplegia than when the paralysis occurs on the opposite side To date however there appears to be no one distinct cerebral area which when stimulated will consistently produce a contraction of the bladder wall

Autonomic Nervous System The term autonomic nervous system as Fulton (56) has stated is used to describe the nerves ganglia and plexuses which supply the innervation of smooth muscle and glandular tissue throughout the body and is characterized by synaptic junctions in ganglia outside the central nervous system Langley (86) limited the meaning of the autonomic system to *efferent* outflow even though many of the nerves also carry visceral afferent fibres. This practice has continued The reason for this concept is that anatomically the afferent fibres are similar to those of the somatic system They simply arise from visceral structures and run the same course as the autonomic efferent channels

Langley (81) divided the autonomic system into two divisions the sympathetic and parasympathetic both of which differ from the somatic system by having synaptic junctions outside the central nervous system The differentiation between sympathetic and parasympathetic is based on the point of outflow from the central nervous system the distribution of the ganglia and the antagonism in physiological effects on visceral tissue which receive innervation from both divisions Synapses of the parasympathetic division are found in the tissue innervated but synaptic junc

tions in the sympathetic system are in a chain of ganglia or in paravertebral plexuses

Sympathetic nerves arise from cells in the lateral horn of the grey matter of the spinal cord and leave the cord in the ventral roots of the thoracolumbar region They emerge from the corresponding spinal nerve at a point distal to the junction of the grey ramus in the form of a *white ramus communicans* According to Sheehan (167) white rami are derived from the first thoracic to the second lumbar nerves inclusive

Many preganglionic fibres in the white rami proceed to ganglia in the sympathetic trunk others lead through this chain to prevertebral plexuses and perhaps some go directly to prevertebral plexuses

Postganglionic fibres emerge from prevertebral plexuses in the coeliac, renal and mesenteric regions to form a plexus in front of the bifurcation of the aorta known as the superior hypogastric plexus (presacral nerve) Sixty per cent of the fibres in this region are said to be medullated and a few ganglion cells are also reported in this plexus The distinctness of individual nerves and the total width of the plexus is variable

Below the promontory of the sacrum the plexus divides into right and left lateral divisions known as the hypogastric nerves (inferior hypogastric plexus) and descends into the depths of the bony pelvis Gross dissections by Ashley and Anson (2) (Figs 2 3 and 4) disclose that deep in the pelvis these nerves are close to fibres of parasympathetic nerves (from S 2-4) and with them form a flat band like structure called the pelvic plexus, in which the sympathetic fibres lie lateral to the parasympathetics Sympathetic nerves from the pelvic plexus lead to other smaller plexuses and

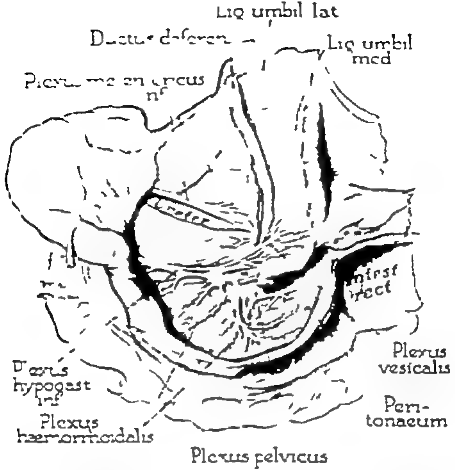

FIG. 2. Topography of the plexuses, ureter and ductus deferens subperitoneal level. Showing the structures related to the pelvic colon and rectum, namely ureter bladder, ligaments and nerves The parietal peritoneum of the lesser pelvis has been removed, and, additionally the vesical part of the visceral peritoneum. The serous layer remains as the pelvic mesocolon, the covering of the colon and rectum, the rectovesical fascia and also as the bilaminar septum which descends between the bladder and rectum (fascia of Denonvilliers marked by arrow here) The ureter ductus deferens umbilical ligament (obliterated artery) and nerves have been freed from the thin stratum of subperitoneal aerolar tissue.

(From Ashley and Anson, *Surg Gynec & Obst.*, 82-600 1946)

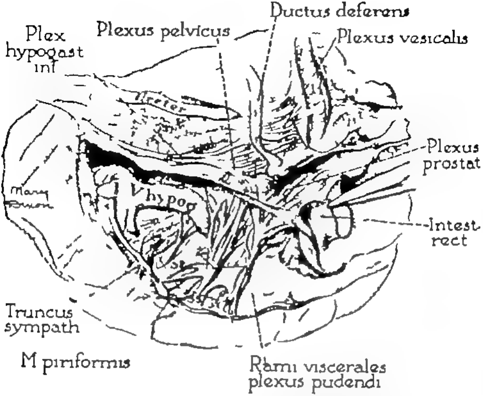

FIG 3 Relation of the hypogastric plexus to the terminal vesical plexus, and to the deeper rami derived from the sacropudendal plexus. The latter are situated at parietal level. Depicting the rectum, urinary bladder ductus deferens, ureter pelvic autonomic nerves, and related structures The following have been removed pelvic colon proximal part of rectum (distal segment retracted) superficial leaf of autonomic nerves to the point of severance of the rectum (opposite fifth sacral vertebra) The nerves are followed toward the rectrovesical excavation the ductus deferens is mobilized as far as its point of junction with the seminal vesicle, where the associated nerves lie within the rectrovesical fold The hypogastric and gluteal veins are exposed The sacral sympathetic chain, with communicating fibres from the second to the fourth sacral is exposed as is also the subajacent piriformis muscle The layers shown are in succession hypogastric and pelvic plexuses lodged chiefly in subperitoneal aerolar tissues heavy retroperitoneal connective tissue, upon which the visceral branches of the above named plexuses rest or through which they pass visceral rami of the sacropudendal plexus of nerves musculature (piriformis passing from the sacrum through the greater sciatic foramen)

(From Ashley and Anson, *Surg Gynec & Obst* 82 601 1946)

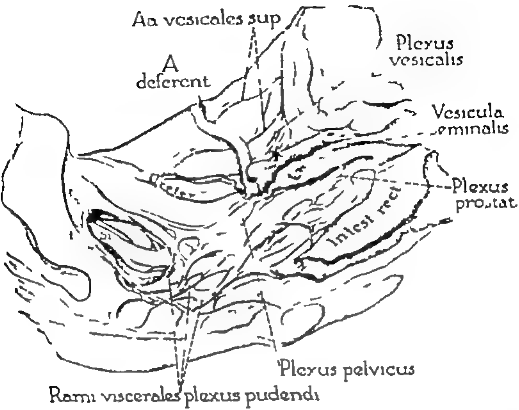

FIG 4 Form and composition of the deeper leaf of nerves. Showing the pelvic plexus, the superficial leaf of which has been entirely removed to expose the deep layer of the pelvic autonomic plexus and the nerves contributing to its fabric. The nerves from the second to fourth sacral (erigens) remain intact, and the anterior continuation of the pelvic autonomic plexus has been followed ventralward to the bladder seminal vesicle, and prostate The rectum, transected at coccygeal level has been retracted The large vein which overlays the first sacral nerve has been removed. The superficial group of vessels is exposed (superior and middle vesicular arteries from the obliterated hypogastric) the deep vessels (hypogastric and external iliac) remain covered by the heavy lamina of the pelvic fascia The main mass o the plexus is parietal in position, resting upon tissue which in turn lies immediately upon the obturator fascia

(From Ashley and Anson *Surg Gynec & Obst* 82 602 1946)

thence to the bladder, prostate, seminal vesicles and proximal urethra.

Small fibres from the sacral portion of the sympathetic trunk also join to send filaments toward the bladder

It has been believed that sympathetic nerves are distributed to the bladder wall and the region of the bladder neck but Langworthy (92) maintains that studies in the cat limit their distribution to the trigone, Bells muscle, cresta urethrae and the blood vessels of the bladder Recent gross dissections in man by Ashley and Anson however, do not suggest any lack of distribution of sympathetic fibres to the bladder itself

Parasympathetic nerves that supply the bladder arise from cells in the lateral grey matter of the spinal cord and emerge in the ventral roots of the second, third and probably fourth sacral segments The medullated preganglionic trunks formed from the branches just mentioned are known as the pelvic nerves or N Erigentes (right and left) and proceed close to the wall of the bony pelvis to the region of the pelvic plexus The pelvic nerves lie medially to the sympathetic fibres in the plexus and continue to the bladder Synapses may occur in the pelvic plexus or in the bladder wall itself

Somatic Nervous System Nerves of the somatic system which are distributed to the region of the bladder may be either motor or sensory

Motor nerves of this system related to bladder physiology arise from anterior branches of the second third and fourth sacral nerves to form the pudendal nerve (internal pudic) which leaves the pelvis through the greater sciatic foramen crosses the spine of the ischium and re enters the pelvis through the lesser sciatic foramen After accompany

ing the internal pudendal vessels along the lateral wall of the ischio-rectal fossa it divides into two branches, the perineal nerve and the dorsal nerve of the penis (or clitoris) The perineal nerve gives off muscular branches which are distributed to the external urethral sphincter (compressor urethrae muscle) and to the muscles of the perineum

Sensory nerves afferent from the bladder and adjacent regions are probably present in the sympathetic, parasympathetic and somatic trunks Fulton emphasizes the fact that most afferent neurones are so constructed that each may excite motor units in several spinal segments

Although the sensory fibres run in the autonomic trunks they are not a part of the autonomic system Further evidence on this point as originally presented by Langley is found in the work of Nesbit *et al* (130) Following parenteral administration of tetra-ethyl ammonium bromide there was evidence of blockage of transmission of nerve impulses over both sympathetic and parasympathetic channels The voiding contraction of the bladder was either diminished considerably or abolished although the ability of the bladder to maintain an approximately constant intravesical pressure with varying volumes of fluid was not abolished Visceral sensation in all the bladders studied by them was totally unaffected by the drug thus presenting conclusive evidence that sensory fibres from the bladder should not be considered as part of the autonomic system

During clinical studies Riddoch (155) observed that with a lesion above the sixth thoracic segment visceral sensations were entirely absent In cases with transection between the sixth and eighth thoracic segments bladder and bowel distention sometimes produced an uncomfortable sensation which was referred to the epigastrium

Later clinical studies by Riddoch (156) indicated that a severe lesion at the level of T 11 would abolish vesical sensibility He concluded that in man the main afferent fibres of the inferior hypogastric nerves lie between the eleventh thoracic and third lumbar segments of the spinal cord D Arcy McCrae and MacDonald (37) believe that there is evidence to indicate that sympathetic trunks transmit sensory impulses in man as well as in animals Denny Brown and Robertson (40 41) also believe that a sense of dull pain in the lower abdomen and adjacent regions when the bladder is distended may be carried by sympathetic channels although McLellan (106) has stated that thoracolumbar sympathetic fibres carry no sensory components from the bladder

Studies by Learmonth (95), Riddoch (156) Langworthy (91) and others indicate that painful sensations from the bladder base trigone and proximal urethra are carried in sympathetic trunks and may join the spinal cord as high as the ninth thoracic segment.

Riddoch found that with complete bilateral lesions of the cauda equina involving the last four sacral roots the penis and urethra were entirely anesthetic, but a patient could be aware of a full bladder Touch sensation in the region of the trigone and adjacent bladder wall could also be recognized

Langworthy has reported that the principal afferent fibres concerned with muscle sense and superficial sensations over the dome of the bladder are carried in tracts leading to the second and third sacral segment of the spinal cord It is believed that painful sensations from the dome of the bladder and the common sensation of the need to void are carried in the parasympathetic trunks

The pudendal nerves convey proprioceptive sensations from the region of the external sphincter

ACT OF URINATION

Micturition is a reflex act even though in the normal it is under voluntary control The reflex activity is dependent on increased intravesical pressure which initiates a stretch reflex and leads to contraction of the detrusor muscle The bladder muscle is not a simple elastic organ

Mosso and Pellacani (111) found that in normal men an intravesical pressure of 18 cm of water usually produced a desire to urinate They found the desire to void was closely related to intravesical pressure but not necessarily related to the quantity of fluid in the bladder Their studies also disclosed that the bladder could accommodate increasing increments of fluid (within limits) at a constant intravesical pressure by undergoing a diastole Likewise with partial evacuation of its contents the bladder appeared capable of systole to avoid a reduction of intravesical pressure to zero The fine contribution by these same authors revealed that psychic reactions have an influence on intravesical pressure Thus it can be seen that bladder muscle has many interesting properties

To return to the physiological steps in the act of urination we repeat the concept of sensory impulses being carried in parasympathetic trunks as the result of increased intravesical pressure and initiating the stretch reflex These impulses are carried to the sacral segments of the spinal cord to contact efferent parasympathetic neurons Efferent impulses over parasympathetic channels lead to vigorous and sustained contraction of the detrusor muscle in the bladder wall

In order for micturition to occur urine must pass the bladder neck. Although not completely understood, the physiology of the bladder neck needs brief discussion From cystoscopic observations and both resting and voiding cystograms Uhle (186) concluded that the internal sphincter is the muscle which closes the vesical orifice and retains urine in the bladder There are three possible ways by which the bladder neck may open at the time of urination They are 1 passively, 2 inhibitory impulses via the parasympathetics 3 inhibition via sympathetic nerves Gruber (62) has stated that experiments have supported all three of these possibilities

Denny Brown and Robertson (40) found that the pressure necessary to open the bladder neck during micturition was not constant and varied between 18 to 43 cm of water This pressure caused by reflex contraction is lower than intravesical pressure produced by voluntary tightening of the abdominal muscles, yet without actual contraction of the detrusor no relaxation of the bladder neck occurs They believed that the internal sphincter contracts and relaxes in reciprocal relationship with the detrusor muscle It is not under voluntary control and its action is believed to be secondary to detrusor activity

Muellner (112) recently reported a fluoroscopic study of bladder activity in the normal human after filling the bladder with a nonirritating opaque medium He found that the first visible steps in voluntary micturition were a downward tug in the region of the internal sphincter of the bladder (presumably caused by relaxation of the muscles of the pelvic floor) and an increase in intra abdominal pressure associated with a fixed diaphragm at the end of inspiration

The contraction wave of the detrusor muscle began in the region of the trigone proceeded along the bladder base and up each side of the bladder so that temporarily the vertical diameter of the bladder became increased and the horizontal diameter became decreased The dome of the bladder then contracted directing the hydrostatic force downward toward the bladder neck and urethra at which time urination occurred

Following experimental studies in cats Langworthy Drew and Vest (91) concluded that the vesical orifice was pulled open by contraction of the detrusor and by the rise in intravesical pressure

Further study is needed before positive statements on the mechanism of bladder neck physiology can be made The relaxation is not wholly dependent on detrusor contraction or high intravesical pressure after spinal cord injury as will be seen later in this chapter

The action of the detrusor and internal sphincter mechanism described above is believed to initiate another reflex that results in relaxation of the external sphincter, following which urination takes place

So far our description of urination has been limited to the reflex aspects of this act The voluntary influence originates in higher centers of the central nervous system exerts an inhibitory effect on reflex contraction of the detrusor and lengthens the interval between voidings Furthermore this inhibitory action may be augmented by voluntary contraction of the external sphincter

In summary the stretch reflex leads to reflex contraction of the bladder and can cause urination Inhibition of detrusor activity and contraction of the external sphincter at higher centers permit voluntary control

OBSERVATIONS OF NERVE STIMULATION AND INTERRUPTION

There have been many interesting experimental and clinical observations on the effects of stimulation and interruption of nerves to the bladder Some of these observations will be reviewed in the hope of providing a better understanding of bladder physiology even though part of the data appear inconsistent In order to be as specific as possible the sympathetic, parasympathetic and somatic systems will be regarded as units and the effect of stimulation or interruption noted in each case

Sympathetic Nerves Information about the influence of sympathetic nerves on bladder action has been obtained from man and experimental animals

Stimulation of sympathetic nerves to the bladders of patients during surgery has been observed by Learmonth (95) who found the following effects contraction of ureteral orifices increase in tone of trigone contraction of internal sphincter contraction of prostatic musculature, contraction of seminal vesicles and ejaculatory ducts contraction of blood vessels of trigone and no change in the dome or lateral walls of the bladder

Stimulation of sympathetic nerves to the bladder of animals has led to variable findings depending on the animal chosen the degree of distention of the bladder at the time of the experiment and the intensity and duration of the stimulus Gruber (62) believes that the variability of response to sympathetic stimulation is primarily dependent on the tonus and degree of irritability of the organ at the time of stimulation MacDonald and McCrae (101) insist that the nature and degree of anesthesia used for the experiment influence the response

Griffiths (60, 61) found that in dogs, stimulation of sympathetic nerves produced relaxation of the bladder if it were in a state of tonic contraction prior to the experiment

The effect of stimulation of sympathetic nerves upon intravesical pressure in cats appears somewhat variable According to Langworthy (92) there is a brief rise in pressure followed by a slow fall to a point below the original level As the quantity of fluid in the bladder increases the relaxation effect is less well defined As a near capacity volume is reached stimulation of sympathetic nerves again produces a fall in intravesical pressure

More recently, Hegre and Ingersoll (69), have again demonstrated the dual phasic response (contraction or relaxation) of the detrusor muscle in cats following electrical stimulation of the hypogastric nerves The experiments were done on animals under light nembutal anesthesia with variable degrees of bladder distention in order to study the response of various portions of the detrusor to sympathetic stimulation All parts of the detrusor participated in the diphasic type of response The physiologic state of the bladder at the time of stimulation of the sympathetic nerves determined the magnitude of each phase In general, the response consisted of an immediate, rapid and unsustained increase in intravesical pressure followed by a gradual decrease to and below the pre stimulatory level

Langworthy (91) and co-workers generally agree that higher pressure is required to force fluid through the urethra in cats during stimulation of the sympathetics but believe that the level of urethral resistance or contraction is at the level of the prostate rather than the bladder neck They believe the phenomenon is due to contraction of muscles of the ureter Bell s muscle and the crista They do not agree

with Elliott (43) that a variable area of muscle on the dorsal bladder wall of the cat is supplied by sympathetic motor fibres

The effects of interruption of sympathetic fibres (in the presacral region) to the bladder in man has been described by Learmonth (95), who found ureteral orifices open internal sphincter and trigone relaxed, blood vessels of trigone dilated, and the bladder wall unchanged. These changes were less evident three weeks after operation Subsequent reports by others have not supported the early enthusiasm for this type of operation designed to relieve certain bladder disabilities and Munro (121) has demonstrated that there is no change in bladder physiology in women following this type of procedure. D Arcy McCrae and MacDonald (37) maintain that there is no evidence that the sympathetics influence the internal sphincter and no evidence that the sympathetic fibres have a purely excitor or inhibitory action on the normal bladder as a whole It is agreed, however that some sensation can be transmitted over sympathetic paths

The older generalization that there is effective antagonism between the sympathetic and parasympathetic systems is not valid

Parasympathetic Nerves Evidence of the influence of parasympathetic nerves on the bladder can be gained from observation of interruption of these nerves in man and from experimental stimulation and interruption in animals

Bilateral stimulation of parasympathetic nerves to the bladder in animals by well known contributors such as Budge (21) Griffiths (60 61) Elliott (43) Langley (86) and Barrington (5) produced a rise in intravesical pressure except when the bladder was in a state of tonic contraction in which case relaxation ensued When stimulation was uni

lateral contraction was limited to the corresponding side of the bladder When parasympathetic fibres on one side had been interrupted stimulation of corresponding nerves on the other side at a later date caused contraction of the whole bladder musculature

Evans (48) ingeniously recorded nervous activity over motor pathways to the bladder by means of a recording oscillograph He found increased activity when the bladder was sufficiently distended and thus led to a concerted effort to expel its contents A simultaneous increase in the discharge to the internal sphincter apparently inhibited an inherent tone and resulted in relaxation when the detrusor contraction was a powerful one Likewise the same type of observation on sensory nerves from the resting bladder showed a rather low rate of discharge However when the bladder wall was stretched by distention a significant increase of discharge occurred over these nerve fibres

The effect of interruption of parasympathetic channels to the bladder in man can be observed in patients with a destructive lesion in the cauda equina Complete bilateral interruption of these fibres causes urinary retention and the voluntary type of micturition is impossible Overflow incontinence follows and is associated with minor contractions of the detrusor muscle Later increased tonicity of the bladder wall is common A few cases have been reported in which vigorous sustained reflex contractions developed Detailed aspects of clinical findings will be described later

Bilateral section of parasympathetic nerves to the bladder in animals gives results similar to those in man Experiments by Elliott (43) Barrington (5) Langworthy (92) and others show retention of urine and distention of the bladder following bilateral section Recovery to a state of periodic

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Experimental observations by Evans (48) indicated that when relaxation of the external sphincter takes place during voiding a cessation of nerve impulses could be demonstrated over the pudendal nerves leading to the bladder

Section of the pudendal nerves in man does not produce any interference with urinary control or the efficiency of urination Either the external sphincter *or* the bladder neck region can be disturbed without loss of voluntary control Unilateral pudendal neurectomy was tried by Huggins Walker and Noonan (80) in six patients with vesical atony They reported moderate improvement and a weakened anal sphincter as the only consistent findings

Emmett, Daut and Dunn (45) recently studied the effect of bilateral pudendal nerve block in individuals with no neurologic lesion All subjects could void normally urination could be induced at will and no incontinence occurred in various body positions

Barrington reported some incontinence in cats after bilateral section of the pudendal nerves but Langworthy found no noticeable evidence of urinary leakage in similar experiments Beattie (8) quotes Dennig to the effect that voluntary control over bladder action can continue after section of the pudendal nerves

Griffiths demonstrated that in dogs resistance offered by the urethra was the same in the living and the dead and that it remains the same after division of the pudic nerves or after transection of the lumbar portion of the spinal cord

Watkins (191) also believed the external sphincter undoubtedly was paralyzed in cases of spinal cord injury In several cases of cauda equina injury the bladder neck was found to be dilated but no incontinence occurred He concluded that the resistance in the urethra was due to pressure

involuntary micturition occurred but complete emptying of the bladder by a forceful stream was not common Elliott found that normal micturition occurred after unilateral section of parasympathetic nerves

Langworthy demonstrated hypertrophy of muscle fibres to account for thickening of the bladder wall after interruption of parasympathetic channels When unilateral section was done this change in the bladder wall occurred principally on the paralyzed side

After removal of both the parasympathetic and sympathetic nerve supply to the bladder in animals Elliott noted *that the bladder wall was still capable of minor waves of* contraction sufficient to cause small quantities of urine to be emitted from the bladder but the contractions were neither rhythmical nor forceful Perhaps this action is facilitated by the nerve net in the bladder wall as described in a review by Zimmerman (199)

It becomes evident that the parasympathetic nerves are *the* important nerves for the proper and normal function of the bladder

Somatic Nerves The pudendal nerves supply the compressor urethral muscle (external sphincter) and accessory muscles of urination such as the ischiocavernosa and bulbocavernosa. The external sphincter is maintained in a closed position and opens during urination only after the bladder neck has opened Denny Brown (41) has proved that voluntary effort can produce a prompt and forceful contraction or closure of the external sphincter but that it cannot be opened or relaxed by voluntary stimuli

Semans and Langworthy (164) demonstrated that in animals stimulation of the distal portion of the severed pudendal nerve produced rhythmic contractions of the ischiobulbocavernosus muscles

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and elasticity of tissue surrounding the urethra in the region of the triangular ligament.

Experimental studies in the cat by Langworthy Drew and Vest (91) indicated that the collapsed urethra offered a certain resistance to the escape of urine which was not affected by section of the pudendal nerves sacral roots or sympathetic fibres

INFLUENCE OF DRUGS ON BLADDER ACTION

Despite considerable experimental work describing the influence of drugs on bladder physiology there are few positive statements which can be applied clinically with effect Discussion presented here is therefore necessarily brief

Henderson and Roepke (72) found support for the old idea that the purely anatomical division of the autonomic nervous system into sympathetic and parasympathetic divisions is pharmacologically meaningless at least as it concerns the characteristics of postganglionic fibres The same authors (71) also presented data to indicate that there is both a cholinergic tonus mechanism in the bladder as well as a contractile mechanism of a different type

Langworthy Kolb and Lewis (92) summarize their opinions by stating that in man atropine may decrease the activity of the stretch reflex to relieve urgency and frequency and that the new compounds of acetylcholine will stimulate strong vesical contractions

At present there are at least two products capable of acting as parasympathetic stimulating agents that are available namely Urecholine and Furmethide Lee (96) has reported that Urecholine increased the tone and contractility of the normal bladder and the type showing hypotonic dysfunction Likewise Furmethide causes increased intravesical pressure and increases detrusor response

MECHANISM OF VOLUNTARY CONTROL OF URINATION

Bladder physiology is interesting because action is motivated through autonomic nerves and yet can be controlled by voluntary impulses Voluntary control of urination implies cerebral activity as part of the mechanism Experimentally it has been possible to cause contractions of the bladder by stimulation of various portions of the brain Studies in animals by Langworthy and Kolb (88) showed that there is a mechanism in the region of the cerebral motor cortex controlling the function of urination as a whole and that in the mid brain there is an area that influences tone of bladder muscle Langworthy (92) concluded that there is evidence of cortical representation over the function of micturition and that the coordination of vesical function was dependent on reflex arcs through the mid brain

It is believed that voluntary retention of urine between each urination is due to inhibitory impulses that originate in the cerebral cortex The voluntary removal or cessation of inhibitory impulses permits the stretch reflex mechanism of the bladder to predominate and results in micturition According to Fulton the concept of *inhibition* was elaborated by Webbers who conceived a possible wider implication of the fact that stimulation of the vagus nerve stopped the heart beat

Studies by Denny Brown and Robertson (41) showed that willed effort can produce powerful contractions of the bladder which in their form and rhythm do not differ from spontaneous contractions of the bladder This is believed to occur not as the result of voluntary excitation but as the result of eliminating inhibitory impulses, either conscious or

unconscious They also believed that by voluntary restraint of urination, vesical contractions can be stopped

After fluoroscopic studies of bladder activity Muellner (112) suggested that voluntary control of micturition begins by relaxation of the somatically supplied pubococcygens muscle thus causing the region of the internal sphincter to drop down and initiate a reflex detrusor contraction As has already been mentioned, the reflex contraction begins in the region of the bladder neck, spreads from the bladder base up the sides and to the dome of the bladder

At the time of voluntary interruption of the urinary stream Muellner found the liquid medium stopped at the bladder neck (not farther down at the external sphincter) thus indicating that voluntary cessation of voiding is pre sumably brought about by combined action of the perineal muscles including the levator ani and pubococcygens and not by the internal sphincter mechanism itself

There is however no evidence to indicate voluntary con trol of the state of the bladder neck (internal sphincter) This region appears to be dependent on and in reciprocal relationship with the detrusor muscle and is closed to the passage of urine except during contractions of the detrusor sufficient to produce urination

The external sphincter can be closed but not opened voluntarily

THE BLADDER AFTER INJURY OF THE SPINAL CORD

Severe injury of the spinal cord produces a profound effect on bladder activity

We know from recorded observations in man and in animals that in the absence of complications time contributes

to changes in bladder physiology Time is an important though variable factor in these changes The immediate disturbance in the bladder and subsequent changes may be spoken of as stages of the *natural process of recovery* Knowledge of these phenomena is imperative to properly interpret the status of the bladder at a given time to venture some opinion regarding the eventual end result and to evaluate various forms of treatment.

Even though it had been known that in animals bladder activity resumed function after spinal cord injury Kidd (82) stated that before World War I patients seldom recovered from paraplegia It was considered that a bladder once paralyzed was not likely to recover An automatic bladder was considered an extreme rarity Kidd emphasized the importance of the work of Head and Riddoch (67) in demonstrating the possibility of establishing an automatic bladder in war casualties

Holmes (77) studied the recovery of bladder activity after spinal cord injury by cystometric examinations and found that it passed through three phases or stages which were not abruptly separated. Munro (118) also reported three stages in the recovery process if the transection was above the sacral segments When the cord lesion was due to hematomyelia or edema at any level he believed four stages could be identified.

Our own observations on patients injured in the recent war were confined to examinations beginning not earlier than several weeks after injury However we were able to follow the patients in our series for a period of twelve to fifteen months and recorded cystometric studies periodically during that time We were able to identify three stages of recovery although the cystometric picture during the third stage is de

pendent on whether the transection is partial or complete

The duration of each stage is variable and is subject to fluctuation depending on the presence or absence of complications not only in the urinary tract but in other parts of the body These stages should be considered as recog nizable but merging phases of a gradual and continuous de velopment

Before considering the three stages in the natural process of recovery in some detail we must consider a phenomenon known as spinal shock which dominates the findings in the first stage of recovery

Spinal Shock Following serious injury of the spinal cord there is an immediate but usually temporary suppression of all reflexes caudal to the injured segment Fulton says that Marshall Hall first used the term spinal shock to de scribe this condition in 1843 The term has continued in good usage and more recently has been defined by Munro (119) as that condition which when caused by spinal in jury of any type produces suppression or alteration of seg mental reflex activity below the level of the cord injury

Spinal shock occurs in all vertebrates and Fulton has stated that its intensity varies with cerebral development. This is consistent with the observations of his associates that the severity and/or duration of the phenomenon is progres sively manifested in the cat, dog monkey chimpanzee and man.

Studies by Fulton Liddell and Rioch (54) demonstrated that in the cat spinal shock did not occur unless the ventral quadrant of the spinal cord was sectioned Later Fulton and McCouch (53) stated that in man section of the cortico-spinal tract leads to spinal shock Fulton further suggests that the present concept of spinal shock indicates a suppres-

sion of reflexes caused by sudden withdrawal of continuous excitation which normally occurs from suprasegmental levels via the descending pathways

First Stage of Recovery After injury of the spinal cord the bladder, as a reflex organ, is immediately affected and dominated by spinal shock. This is manifested by atonicity of the bladder wall and loss of reflex contractions of the detrusor Thus the bladder becomes distended to large capacity reaching to or above the umbilicus Overflow incontinence may occur after a period of twenty four to forty eight hours and is the only type of urination that can be expected

Cystometric studies during this stage show a bladder capable of large capacity with low intravesical pressure and without evidence of reflex detrusor activity It has been called an atonic neurogenic bladder Holmes (77) found no pressure recorded until four to eight ounces had been introduced into the bladder The pressure then rose slowly to a level of 8-10 cm of water after twenty ounces had accumulated On emptying the pressure curve repeated itself In other words at this stage the bladder presented only the property of elasticity The presence of cystitis caused no change in the cystometric record during this stage and the findings were the same for injury at all levels of the cord or cauda equina He found that this phase lasted from days to weeks According to Thomson Walker (184) this stage may last from twenty four hours to eighteen months

The difficulties that arise from lack of precise definition are evident in the term of atonic neurogenic bladder Nesbit and Lapides (131) made cystometric observations on patients under spinal anesthesia and in two patients with spinal cord injury who were placed on constant drainage

pendent on whether the transection is partial or complete.

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transection at the level of the sacral segments or cauda equina

Third Stage of Recovery Further recovery of the bladder to a third or final stage will depend on several factors namely the extent of the injury of the spinal cord, the level of the injury, the general condition of the patient and the severity of infection in the bladder

The type of bladder to be hoped for in the final stage of the recovery process is dependent on whether the transection of the spinal cord has been partial or complete In order to clarify our position on this point the following statements should be made

Cases designated as having *complete transection* show complete functional interruption of the spinal cord at a given level over a long period of time

In some cases complete division of the cord can be demon trated during surgical visualization Others who may not have had laminectomy have shown no evidence of voluntary motor power or return of sensation below the level of the injury during a period of at least six months after injury

It is expected that the bladder of the patient with *complete transection* will progress to a final stage in which *periodic involuntary forceful and efficient* micturition is characteristic.

The patient in this final stage has no voluntary control over the periodic reflex voiding but during the one to four hour intervals between voidings there is no leakage of urine We have observed that frequently the intervals between urinations are much longer with the patient in the sitting position than when he is flat in bed The reason for this however is not clear The patient with this type of bladder be

before bladder distention had a chance to occur In both instances cystometric pressure was 10 12 cm of water at 300 cc. 22 cm at 500 cc. and 28 cm at 600 cc. (in one patient) Although these readings are lower than in one cystometrogram (Fig 8) that I have designated atonic bladder, Nesbit and Lapides feel that such curves do not show atonicity Perhaps hypotonocity might be more descriptive Except for waves of reflex contraction it is often difficult to differentiate between the tone of a normal and hypotonic type of bladder

Nesbit and Lapides believe that overdistention of the bladder is the cause of atonicity

Second Stage of Recovery In a variable period of time a return of mild reflex activity caudal to the injured segment usually becomes evident and produces changes in the activity of vesical musculature The progression from the first to the second stage occurs gradually but can be demonstrated by cystometric study The bladder has a smaller capacity intravesical pressure is increased and the curve rises more rapidly Reflex contractions of the bladder wall can be observed but they are of insufficient strength or duration to produce efficient emptying of the bladder Munro (119) believes that these contractions are due to a reflex arc that lies wholly within the bladder wall For that reason this stage has been given the name autonomous cord bladder and is manifested clinically by overflow incontinence

The amount of residual urine in the bladder is smaller than during the first stage, perhaps because bladder capacity is not so great

Lewis (98) Nesbit and Gordon (129) and Munro (118) have stated that the autonomous bladder may be the final stage of recovery in cases which have had complete

spinal cord show some evidence of voluntary motor power and sensory appreciation below the level of the lesion although this may not be evident for several months after injury

It is to be hoped that patients with partial transection will progress a third or final stage characterized by voluntary micturition sufficient to produce efficient emptying of the bladder The necessity for manual pressure over the lower abdomen during micturition straining during voiding and diminished sensation from the bladder region *may* be accompanying features but there is voluntary control The organ under these circumstances might be termed a voluntary neurogenic bladder Bladder capacity is within normal limits and bladder residual is variable

Although the terms complete and incomplete transection have been emphasized because of their importance in predicting eventual outcome and judging results of treatment it is often difficult to state with assurance immediately after injury whether the lesion is complete or not As Riches (153) has stated during spinal shock there can be no reliable data about the degree of nerve injury

The *level of injury* in the spinal cord may also have some bearing on the degree of recovery Even though Denny Brown (42) and Head (68) have recorded cases of complete transection at the level of the conus or cauda equina in which an automatic reflex type of bladder has developed Lewis (98) and Riches have emphasized the fact that patients with complete lesions above the lumbar segments develop an automatic type of voiding much more consistently than those in whom the lesion is below that level

Other factors of importance in the recovery process in

comes familiar with his individual time schedule and learns to govern his activities accordingly

We found that emptying contractions of the bladder usually create an intravesical pressure of 70 cm of water or more Holmes (77) found oscillations of bladder pressure independent of reflex contractions of the legs and did not believe bladder activity a part of a mass reflex. On the other hand Head and Riddoch (67) found that peripheral stimuli often initiated the automatic reflex evacuation of the bladder except in cases of complete transection of the cauda equina

Bladder capacity in this stage varies between 150 and 400 cc

In our series bladder residuals were found to vary between thirty and ninety cc

The term automatic reflex bladder has been used to describe this type of vesical activity It is the normal end of the path of recovery in those who have had complete transection of the spinal cord

Most patients with complete transection can be expected to progress to the final stage just described, but there are a few who appear to remain in the first or second stages of recovery even though the nerve lesion is above T 10 bladder infection is minimal and general condition excellent This limited recovery in a small group of cases is usually associated with continued flaccid paralysis of the lower extremities The cause of the failure of progression to an automatic type of bladder is not known It is possible that lack of vascularity in the distal segment of the spinal cord has led to necrosis with insufficient tissue to permit a suitable reflex arc

Cases designated as having *partial transection* of the

Bladder Among the various types of examination which will prove useful in determining the status of the bladder are cystometry, cystoscopy, cystography urinalysis and the determination of bladder residual

Cystometric study Cystometry can be used to determine bladder tone (relation of the volume of bladder content to intracystic pressure), presence or absence of reflex contractions of bladder muscle, bladder capacity maximum voluntary pressure and sensation to bladder distention Rose (160) has been prominent in pointing out the value of this method for the study of bladder physiology and pathology

Although various forms of instruments for this type of study have been advertised and devised a simple model as shown in Figure 5 easily disassembled and sterilized is apt to prove informative While there is no automatic recording device in the cystometer described here, the observer and recorder of the examination will learn more about the individual patient by closely watching the proceedings than he can infer from a casual glance at any completed record In some models of tidal drainage apparatus cystometric observations can be made without additional equipment

Two features appear important in any apparatus used for this examination A water (or very sensitive aneroid) manometer is required to measure small changes in intracystic pressure A constant drip method of filling the bladder during the determination is to be preferred to the older method of introducing 25 to 50 cc increments of fluid into the bladder at intervals The manometer is never shut off no reflex activity is missed and there is no confusion or delay while awaiting the downward stepladder changes in pressure so common immediately following the sudden introduction of larger amounts of fluid

clude a positive nitrogen balance, freedom from toxic and febrile states and absence of decubitus ulcers The absence of gross infection in the bladder is likewise essential for optimum rate of recovery of this organ Infection in the muscle layers of the bladder followed by fibrosis cannot be be expected to result in acceptable function

As the early treatment of the paralyzed bladder has become improved in the past decade, there are now many more patients living after spinal cord injury All observers have become aware of the various complications that often plague the paraplegic patient and which often cause faulty bladder action

Although the stages of the natural process of recovery of the bladder have been described, we must be aware of the many exceptions and alert to the conditions responsible for the same The numerous discussions of bladder neck resection use of drugs to relax or stimulate the detrusor sacral and pudendal nerve blocks and subarachnoid injections in an effort to rehabilitate the bladder after spinal cord injury serve to warn that restoration of an efficient and socially acceptable bladder action is not always easy

EXAMINATION OF THE BLADDER AND BLADDER NECK

Study of the bladder and the region of the bladder neck is necessary in every case not only for accumulative data but for proper treatment if one is to obtain the optimum result in each patient Perhaps not all of the following methods of examination are applicable in each case nor are they essential during the immediate days or weeks following injury but they will be mentioned so that they may be used selectively

catheterize with sterile precautions using an 18F two-holed (Robinson) catheter Empty bladder and measure the residual urine

4 If patient is already on drainage, release clamp on catheter and empty the bladder

5 Fill the calibrated irrigating jar shown in Figure 5 with sterile water or boric solution of approximately room temperature and unscrew Hoffman clamp above closed Murphy drip bulb to fill rubber tubing and manometer tube Secure Hoffman clamp and permit fluid in manometer tube to drop slowly to zero mark Clamp rubber tube leading toward catheter
MAKE SURE ALL AIR HAS BEEN REMOVED FROM TUBING!

6 Connect apparatus to catheter with glass connecting tube and permit approximately 10 cc. of solution to enter bladder by releasing Hoffman clamp Again secure the Hoffman clamp

7 Adjust manometer tube so that the zero mark is level with pubis of patient and fluid in the manometer tube can be seen gently oscillating as respiratory waves at the zero mark (Respiratory waves usually have a 1 to 3 cm water excursion)

8 Note level of fluid in irrigating jar so that manometric readings may be correlated with the gradual increase in bladder content

9 Instruct patient to relate any sensation of desire to void or discomfort in lower abdomen

10 Unscrew Hoffman clamp above Murphy bulb sufficiently to permit a rate of flow of approximately 125 drops per minute

11 Record manometric pressures on chart as each 25 to 50 cc. increase in bladder content occurs Note and record extent of reflex contraction waves

12 Record any sensations of desire to void

13 Occasionally record the increased manometric pressure when patient is asked to strain in attempt to void (maximum voluntary pressure)

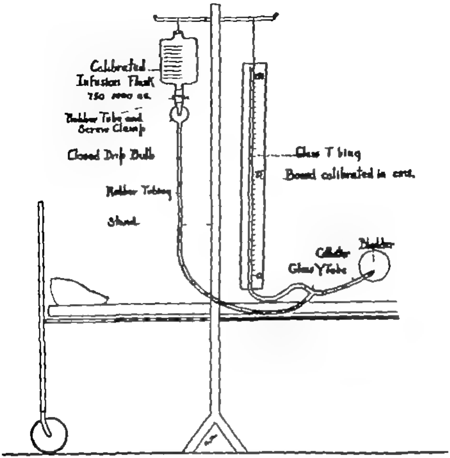

FIG. 5 Simple cystometer using principle of constant drip filling of bladder and the indication of intravesical pressure in cm. of water The set consists of an infusion bottle, rubber tubing Hoffman clamp closed Murphy drip bulb Y glass tubing straight glass tubing and board calibrated in cm Apparatus should be autoclaved between individual studies

Recommended procedure for examination with the model shown in Figure 5 is as follows

1 If patient is not on drainage instruct him to void, if possible and determine the amount
2 Have patient in supine position on bed litter or examining table
3 If patient is not on drainage cleanse genitalia and

Munro (117) described three types of normal bladder activity as demonstrated by cystometric study One in which spaced emptying like contractions occurred throughout the experiment 2 One in which emptying contractions occurred toward the end of a 400 cc fill in the form of unspaced tetanic contractions and, 3 One in which there are no emptying contractions until over 400 cc have been introduced into the bladder In a study of normal individuals however Simeone and Lampson (169) found that spontaneous bladder contractions were practically never seen until a steep rise in pressure occurred Their cystometric curves could be divided into an initial rise a relatively flat area and a final sharp rise

Muschat Carp and Charney (128) stated that too much stress has been laid on the pressure curve They stressed the importance of the composite picture which consists of a The first desire to void b The pressure curve gradually rising and c. Maximal voluntary pressure of 60 to 80 mm Hg

Examples of pressure curves in normal individuals as recorded by Watkins (190) are shown in Figures 6 and 7

Following injury of the spinal cord cystometric findings are immediately altered During the period of *spinal shock* (first stage of recovery) with associated loss of reflexes below the level of injury the pressure curve is low and flat bladder capacity is increased to 500 to 600 cc or more no reflex contractions are evident and sensation of distention is lacking except in low lesions in which painful sensations may be described in the lower abdomen Example of a typical cystometric chart in this stage (often called an atonic neurogenic bladder) is shown in Figure 8

As the bladder begins to show recovery from spinal shock to the *second stage* which has been called autono-

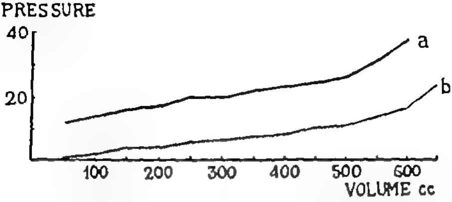

Fig 6 Normal Cystometric Curves Pressure curves in cm of water of the normal bladder at rest Curve a represents the highest and b the lowest curve in a series of examinations. First sensation at 100 cc. in a and at 150 cc. in b

(From Watkins *Brit J Urol* 6 107 1934)

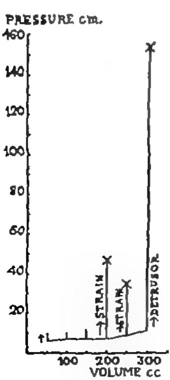

Fig. 7 Normal Cystometric Curve Shows the pressures recorded on a bladder with normal innervation The vertical lines rising from the curve at rest indicate the result of attempted urination. The first three attempts had very little effect A marked increase of pressure resulted at the next two efforts when the man was requested to strain as hard as possible with his abdominal muscles. At the last attempt at urination the micturition reflex has been released and the high pressure which results from contraction of the detrusor muscle is shown. First sensation noticed at 250 cc

(From Watkins *Brit J Urol* 6 108 1934)

cystometric chart will, therefore, differ greatly in the two groups In instances of *complete transection* patients in the third stage with an automatic reflex type of bladder have the following characteristics normal to increased initial tonus variable pressure curve capacity between 150 and 400 cc forceful reflex detrusor contraction with urination when capacity has been reached, no sensation of bladder distention, and frequently variable flushing or sweating reactions in upper part of the body when bladder reflex is about to act

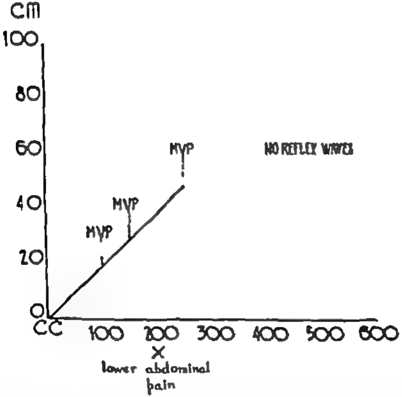

Fig. 9 Cystometrogram illustrating the second stage of recovery in patient with complete transection of mid-dorsal portion of the spinal cord Rise in pressure is rather steep but there are no reflex voiding contractions The lesion is too high to permit more than a 10 cm rise by maximum voluntary pressure (MVP)

mous cord bladder by Munro (118) and McLellan (106) the cystometric chart reflects the following changes: increased initial tonus; fairly steep pressure curve, capacity limited to that of a normal bladder; minor rhythmic detrusor contractions rarely greater than 10 cm. of water and insufficient to empty the bladder, lack of definite desire to void, and in some patients a feeling of lower abdominal discomfort when the bladder is full. A cystometrogram illustrating this stage is shown in Figure 9.

As indicated earlier in this chapter the *third* (*final*) *stage* to which it is hoped all patients will progress depends on whether the transection has been partial or complete. The

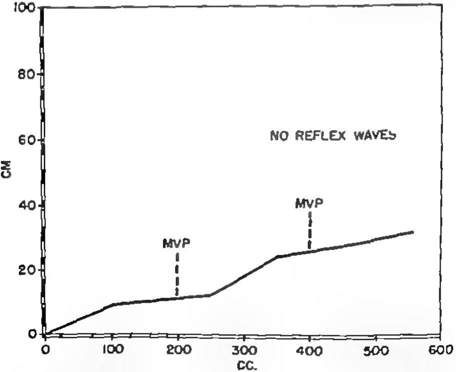

Fig. 8. Cystometrogram showing an atonic bladder, the first stage of recovery following severe spinal cord injury. In a few cases this stage may be permanent although the majority progress to the second and third stages.

sensation are normal Figures 12 and 13 show cystometric studies of patients with partial transection of the cauda equina

In addition to the routine data mentioned above in the discussion of cystometry Mullenix (111) has advocated determination of *active* or *maximum voluntary pressure* routinely throughout the entire process of bladder filling a procedure which we had already followed and found interesting The difference between this value and the usual *passive*

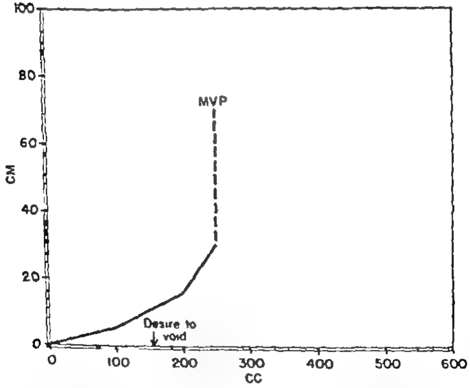

FIG. 11 Cystometrogram in patient with partial transection of cervical portion of the spinal cord. Voiding is now voluntary with perfect control The cystometric data are essentially normal and represent the third or final stage of recovery in partial transections in the upper segments of the spinal cord.
(From Prather *J Urol* 57 23 1947)

Figure 10 illustrates the cystometric chart in this type of patient

In instances of *partial transection* a voluntarily controlled type of urination will show cystometrograms that may be very close to normal, especially when the lesion is in the upper part of the cord. Figure 11 illustrates the cystometric chart in a patient with partial transection in the cervical region. Initial tone, pressure curve, capacity and bladder

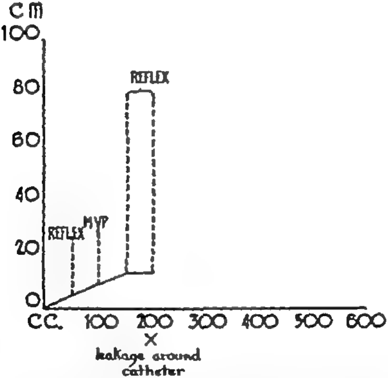

FIG. 10 Cystometrogram illustrating the third or final stage of recovery in patient with complete transection of upper thoracic portion of the spinal cord Reflex contractions occur periodically during constant filling but these are insufficient to produce voiding until 150 to 200 cc. had accumulated in the bladder The patient has an automatic reflex type of urination at fairly regular intervals with no leakage of urine between voidings.

muscles cannot be voluntarily contracted there is little difference between the passive pressure and maximum voluntary pressure

It must be noted that variations are found in cystometric response and that changes from one stage to another do not necessarily occur rapidly Repeated examinations are often required to obtain an accurate impression of the functional capacity of the bladder muscle, and effectiveness in voiding may in turn be influenced by conditions in the region of the bladder neck and urethra.

We are convinced that cystometric studies are a neces-

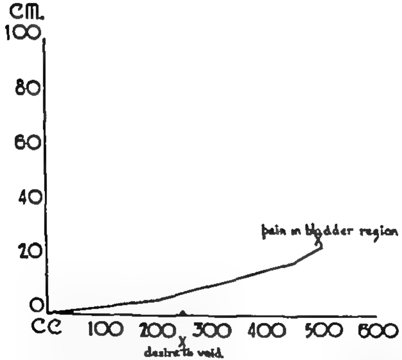

Fig 13 Cystometrogram in patient with partial transection of cauda equina. Recovery to date is not complete Pressure curve is somewhat flattened, but soon after this examination patient developed voluntary voiding which had to be supplemented by abdominal pressure

values during filling was called "expulsive force" by Mullenix who believed this factor important in prognosis of ability to void. Our interpretation of maximum voluntary pressure is that it reflects either paralysis or integrity of muscles of the abdominal wall and its value is primarily dependent on the level (and perhaps extent) of the spinal lesion. In injuries of the conus or cauda equina with no paralysis of abdominal muscles voluntary contraction of these muscles does raise intravesical pressure and may augment the reflex contractions of the detrusor to advantage. In injuries of the upper part of the spinal cord since the abdominal

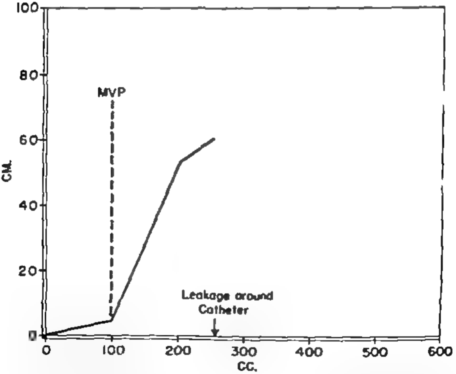

FIG. 12 Cystometrogram in patient with partial transection of the cauda equina. Recovery to the third stage of voluntary voiding has been accomplished. Because the nerve lesion is low maximum voluntary pressure is essentially normal.

No abnormality in the appearance of the ureteral orifices has been found except occasionally edema caused presumably by contact of the catheter or a suprapubic tube that was placed too low in the bladder

Cystographic study Cystography provides indirect observation of the bladder and is useful to determine the general shape of the organ presence and size of diverticula if any spasticity and approximate capacity The cystogram may be obtained by x rays following the injection of 3 or 4 per cent sterile sodium iodide or of 8 or 10 per cent skiodan through a catheter or suprapubic tube As an alternative films of the bladder region about forty five minutes after injection of media for intravenous pyelography often pro-

FIG. 14

FIG. 15

FIG. 14. Cystogram through suprapubic tube in patient with complete transection of dorsal portion of spinal cord. Patient is in the first stage of recovery Bladder is atonic and bladder neck is dilated

FIG. 15 Cystogram in patient with severe lesion of cauda equina Bladder is atonic and bladder neck is relaxed

sary part of the complete study of bladder physiology in patients with spinal cord injury

Cystoscopic study Cystoscopy for inspection of the bladder is not recommended as a routine examination in the early periods of disability However used selectively, it supplements other examinations and at times proves invaluable to discover and deal with bladder stones and to explain abnormal findings in x rays

In the paralyzed patient, the cystoscope should be used only by those thoroughly familiar with the instrument The patient s lack of normal sensation permits too many liberties, and may lead to injury of the lower urinary tract at the hands of the untrained cystoscopist

The cystoscopic picture of the normal bladder will be omitted and remarks confined to changes as seen in the paraplegic patient During the *first* (atonic) *stage* of the recovery process McLellan reported a smooth atrophic type of mucosa with fine trabeculation. In the second stage of recovery we have frequently found moderately heavy trabeculation. During the third stage patients with complete transection who have an automatic reflex bladder show moderate to heavy trabeculation During the third stage patients with partial transection who are voiding effectively with voluntary control show a normal mucosa if the spinal lesion is high and coarse trabeculation if the injury has involved the cauda equina

Trabeculation indicates a thickened bladder wall This is apparently not entirely due to the effort of bladder muscle working to overcome urethral or bladder neck obstruction as it occurs in patients who are still on drainage Hargrave (64) noted a similar finding at autopsy in a patient who had been treated by intermittent catheterization.

Reflux up one or both ureters we have occasionally seen when the cystographic medium has been introduced through the urethral catheter, but this is an infrequent rather than a common finding in the paraplegic patient, at least during the early months after injury When it does occur it is probably the result of an inflammatory change involving the ureteral orifice rather than a direct effect of the nerve lesion Reflux may be found to be more common years after the injury (Fig 17) In 100 routine cystograms in paraplegics Talbot and Bunts (179) found 10 who showed vesicoureteral reflux They noted an obvious change in the cystoscopic appearance of the ureteral orifices in patients who showed reflux a gaping orifice perhaps produced by inflammatory changes or by the influence of a hypertonic bladder — present in all of their cases In none was bladder neck obstruction evident

Urine analysis Examination of the urine contributes to our knowledge of the condition of the bladder Specimens had best be examined at least occasionally by the urologist himself Personal correlation of the microscopic findings and clinical picture is preferable to the usual formal data on a laboratory report Likewise the immediate examination of a freshly obtained specimen cannot be overemphasized

The centrifuged urine sediment carefully examined under the high dry lens (or oil immersion if stained) provides an approximate indication of degree of infection in the bladder although it is not necessarily indicative of the appearance of the bladder mucosa During an acute urinary infection with pyuria the bladder mucosa shows evidence of injection redness and perhaps edema or hemorrhagic areas The bladder mucosa of patients with a mild chronic infection commonly shows no change from the normal but when bacteria are

vide satisfactory data if the drainage tube of the bladder has been clamped off during the examination

During the first stage (spinal shock) the cystogram (Fig 14) should demonstrate a large smooth walled bladder which if filled to capacity would fill the whole bony pelvis A similar picture may also be found in severe lesions of the cauda equina (Fig 15) In the second stage of recovery trabeculations produce irregularity in the periphery of a normal sized bladder In the third stage the cystogram of the distended reflex automatic bladder frequently had a rounded appearance with an irregular border consistent with trabeculation (Fig 16) During the third stage in patients with partial transection the cystogram appears normal except in those with a lesion of the cauda equina, in whom the bladder appears slightly dilated with a slightly irregular margin

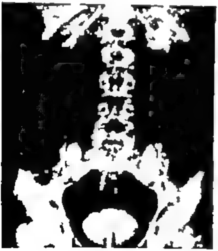

FIG. 16

FIG. 17

FIG 16 Cystogram as part of intravenous urogram in patient with complete transection of the mid-dorsal cord

FIG. 17 Cystogram several years after complete transection of spinal cord in mid-thoracic region. There is reflux up both ureters (Courtesy Dr Charles Ney)

Reflux up one or both ureters we have occasionally seen when the cystographic medium has been introduced through the urethral catheter but this is an infrequent rather than a common finding in the paraplegic patient at least during the early months after injury When it does occur it is probably the result of an inflammatory change involving the ureteral orifice rather than a direct effect of the nerve lesion Reflux may be found to be more common years after the injury (Fig 17) In 100 routine cystograms in paraplegics Talbot and Bunts (179) found 10 who showed vesicoureteral reflux They noted an obvious change in the cystoscopic appearance of the ureteral orifices in patients who showed reflux a gaping orifice perhaps produced by inflammatory changes or by the influence of a hypertonic bladder — present in all of their cases In none was bladder neck obstruction evident

Urine analysis Examination of the urine contributes to our knowledge of the condition of the bladder Specimens had best be examined at least occasionally by the urologist himself Personal correlation of the microscopic findings and clinical picture is preferable to the usual formal data on a laboratory report Likewise the immediate examination of a freshly obtained specimen cannot be overemphasized

The centrifuged urine sediment carefully examined under the high dry lens (or oil immersion if stained) provides an approximate indication of degree of infection in the bladder although it is not necessarily indicative of the appearance of the bladder mucosa During an acute urinary infection with pyuria, the bladder mucosa shows evidence of injection redness and perhaps edema or hemorrhagic areas The bladder mucosa of patients with a mild chronic infection commonly shows no change from the normal but when bacteria are

present in bladder urine there is at least potential cystitis and pyelitis

Badal Munro and Lamb (3), in a careful cultural study of urines of patients on tidal drainage came to the conclusion that bacteria are always present in the bladder seventy two hours after the introduction of an indwelling catheter They found the most common organisms to be Proteus vulgaris, alpha hemolytic streptococcus and Esch coli Our own studies, during military service, on routine cultures taken from the distal end of a urethral catheter or suprapubic tube after several months of drainage showed Pseudomonas aerogenes Proteus vulgaris staphylococci and Esch coli as the most common urinary inhabitants Predominating organisms were found to change from week to week.

There is no doubt that any kind of a tube which is inserted and left in the bladder for more than forty hours acts as a foreign body There is naturally a foreign body reaction consisting of the appearance of leukocytes and evidence of congestion to provide a locus for bacterial growth Bacterial growth ensues but as in other parts of the body if the region is properly drained and cleansed, and if adequate body resistance is maintained, clinical evidence of infection does not develop Therefore a positive culture of the urine with any type of bladder drainage indicates potential but not necessarily actual clinical disease Cultures are advisable however to determine proper medication should clinical evidence of sepsis occur

Experimental studies by David (38) are comparable to clinical experience He injected B Coli into the bladders of normal dogs to find that organisms remained in the urine for a time but no histological evidence of cystitis or pyelitis developed If the animals had a bladder residual however the

introduction of bacteria into the bladder caused ulcerative cystitis and kidney infections After section of the lower dorsal spine of dogs infection in wounds of the back was followed by bladder infection with the same organisms

Bladder Neck Although it is generally believed that the bladder neck, prostatic urethra external sphincter and membranous urethra relax or open after contraction of the detrusor muscle has begun the regions are linked closely in the physiology of the bladder In a complete study of bladder action following spinal cord injury, the region of the bladder neck deserves study as well as the bladder itself Information about this portion of the body can be obtained by cystoscopy with the foroblique lens system or by urethrocystography Sphincterometry as developed by Simons (170) we have not used It may offer possibilities for future observations

Cystoscopic study Cystoscopy in the type of patient under consideration is not to be taken lightly but used selectively and without trauma it may provide valuable data Except for study purposes it should be used only during the latter part of the recovery period to discover changes at the bladder neck which need correction in order to improve bladder function

Although Uhle (186) made cystoscopic and cystographic observations to study the method of bladder closure and Burns (24) used similar methods to study the bladder in a series of tabetic patients Plaggemeyer (138-139) appears to have been among the first to make cystoscopic observations in patients with spinal cord injury He describes complete relaxation of the prostatic urethra and bladder neck. In four cases the trigone appeared raised while in six the trigone was atrophic. Cumming (32) recorded cystoscopic ob-

servations in ten patients with spinal cord injury and described a relaxed bladder neck and a normal or hypertonic external sphincter In further studies Cumming (33) demonstrated a dilated bladder neck during the stage of overflow incontinence and concluded that the internal sphincter is regularly dilated and presumably inactive soon after the onset of paralysis it regains tone in periods of recovery During the recent war many cystoscopic observations were made on patients with spinal cord injury but most have not been recorded in the literature as yet

Personal observations in a series of patients with spinal cord injury may be summarized as follows In patients with complete transection of the spinal cord in the upper and middle thoracic segments who had as yet failed to develop any sign of reflex activity of the bladder wall and who had flaccid paralysis below the level of the lesion, the prostatic urethra and bladder neck were found definitely relaxed and dilated In cases with complete transection of the spinal cord in the upper or middle thoracic segments whose bladder had recovered to the third (or final) phase and who were voiding periodically with an automatic reflex bladder the bladder neck appeared normal for the age group in the majority while in others there appeared to be a slight dilatation of the prostatic urethra Patients with complete transection at D 12 or below invariably showed moderate to considerable relaxation of the bladder neck and prostatic urethra while most of those with partial transection at these lower levels revealed slight to moderate dilatation in the same region When partial transection had occurred in the higher segments of the cord the bladder neck commonly appeared normal The above observations were made through a No 20F panendoscope with foroblique vision

Bumpus, Nourse and Thompson (22) report that cystoscopic examination shows various degrees of bladder neck relaxation but in some they found constriction in the region of the internal urethral orifice so that the bladder and prostatic urethra had an hour glass appearance In other cases they observed a bar type of deformity

Before a complete report can be made of the cystoscopic findings of the bladder neck in patients with spinal cord injury it will be necessary to correlate observations in large series, with a careful breakdown of the various levels and extent of the cord lesion

Cystourethrographic study Cystourethrography and other studies may also furnish information about the condition of the bladder neck In 1933 Denny Brown and Robertson (40) studied three cases of complete transection of the cauda equina by cystometric studies with the proximal tip of the catheter in the bladder in the prostatic urethra and in the bulbous urethra It is difficult to see how they could be absolutely sure about the proximal end of the catheter in the prostatic urethra without x ray especially if the prostatic urethra were dilated as it should be in this type of lesion They stated that the degree of laxity of the (internal) sphincter is directly proportional to the degree of vesical contraction both during actual discharge and during vesical contraction without discharge Denny Brown and Robertson were unable to find any evidence of a functioning external sphincter in their cases although the pressure at which discharge of urine began and terminated was much higher for the external than the internal sphincter

Watkins (191) by *cystography* found wide relaxation of the vesical neck in seven or eight cases with partial transection of the cauda equina and noted variation of bladder

FIG. 18

FIG 19

FIG 18 Urethrogram shows dilated bladder neck in patient in first stage of recovery The dye in the bladder surrounds a stone
(From Prather *J Urol* 57 278 1947)

FIG 19 Urethrogram in patient with complete transection in lower dorsal region. Filling defect caused by tip of suprapubic tube can be seen Bladder neck is dilated.
(From Prather *J Urol* 57 282, 1947)

neck during intervals of only a few minutes He found that even when the internal sphincter was widely dilated there was no escape of fluid. He disagreed with the interpretation of Denny Brown and Robertson according to which the internal sphincter should have been closed in the interval between vesical contractions

Denny Brown (42) has also reported further observations on the bladder neck by cystography In patients with automatic reflex urination he noted that with only 25 cc of opaque solution *in the bladder the region of the internal* meatus had the shape of a small dimple If distention was

continued the dimple widened to a small funnel and the urethra was dilated down to the verumontanum He stated that a funnel type of bladder neck was commonly found in cauda equina lesion because the procedure used to demonstrate it excites contraction of the bladder

Urethrography by the injection of a small amount of opaque material through the urethra from the external meatus should not produce sufficient intravesical pressure to cause reflex detrusor activity This type of examination should disclose the condition of the bladder neck in a resting state Urethrograms illustrating various changes in the bladder neck are shown in Figures 18 to 22

Recent studies of this type were made by Prather and

Fig 20

Fig 21

Fig. 20 Urethrogram in patient with complete transection in lower dorsal region of the spinal cord Patient has good automatic reflex bladder with satisfactory capacity Bladder neck is dilated

(From Prather *J Urol* 57 282 1947)

Fig 21 Urethrogram in patient with partial transection of the cauda equina It shows no change from the normal Patient was voiding voluntarily with good control

(From Prather *J Urol* 57 276 1947)

Petroff (147) in a series of 129 cases of spinal cord injury They found that in 36 cases of complete transection of th cord or cauda equina the bladder neck showed some degree of dilatation in 30 a ratio of 5 dilated to 1 normal In 93 cases of partial transection of the cord or cauda equina there was a ratio of 2.2 dilated to 1 normal

These authors also studied the relation of the level of injury to the bladder neck changes In 29 cases of complete transection of the thoracic portion of the cord the ratio of dilated bladder neck to normal was almost 4 to 1 while all patients with complete transection of the cauda equina had some degree of dilatation at the internal urethral orifice In those with partial transection at various levels they found dilatation of the bladder neck was common and occurred with increasing frequency from the level of the cervical region to the cauda equina

FIG 22 Urethrocystogram in patient with partial transection of the cauda equina. Bladder recovered to permit voluntary voiding supplemented by straining with abdominal muscles. The bladder neck is dilated.
(From Prather *J Urol* 57 278 1947)

In an effort to determine the significance of bladder tone or bladder capacity in urethrographic changes at the bladder neck, Prather and Petroff compared 10 cases with automatic reflex bladders having hypertonic type of bladder with capacity of about 150 cc to 12 cases with other types of bladders having a capacity of over 400 cc Some degree of dilatation was prevalent in both groups

A selected group of patients with spinal cord injury who had had urethrographic studies during a period of bladder drainage were re-examined five to nine months later when they were voiding and free of drainage with tubes. Cases of both partial and complete transection were included. It was found that while there may have been some change in the shape of the prostatic urethra and bladder neck, little or no change in the degree of dilatation was produced by the lapse of time or by the change in status of the bladder.

Data contributed to date by various authors indicate that dilatation of the bladder neck is a common finding in patients with injury of the spinal cord, but the correlation of this observation with detrusor action appears difficult at this time because the dilated bladder neck is common with both the hypertonic and atonic type of bladder, because there is no marked change in dilatation over a period of months involving changes in bladder activity, and because the groups are not absolutely uniform.

CARE OF THE BLADDER

Now that we have some idea of the natural history of bladder physiology after injury of the spinal cord and some knowledge of the various methods of study that can be employed, we must state the objectives and principles involved in the care of the bladder, discuss the various methods of treatment available at present, and state the results of treatment recently employed.

Objectives of Treatment. Our objectives can be stated briefly and simply. The patient should become ambulatory and free of urinary infection. A patient who has sustained a *partial* transection of the spinal cord should attain voluntary control of urination and be capable of emptying his bladder. A patient who has a *complete* transection of the

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FIG. 22 Urethrocystogram in patient with partial transection of the cauda equina. Bladder recovered to permit voluntary voiding supplemented by straining with abdominal muscles The bladder neck is dilated.
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The following opinions have been expressed in regard to this type of treatment Besley (11) reported that infection rarely occurred without catheterization and that distention of the bladder was not harmful either to the bladder or kidneys During World War I Vellacott and Webb-Johnson (187) observed sixty six cases in a forward area for an average period of three weeks Most of the patients had been injured only one to seven days previously Of ten cases which had not been catheterized 10 per cent showed urinary infection In forty cases which had been catheterized seventy seven per cent were infected They preferred a non-catheter program but realized that infection occasionally occurred without catheterization Kidd (82) also observed casualties in World War I and stated that the Crede method of emptying the bladder was used in France in 1917 but he believed many cases became infected and did not favor the non drainage program David (38) stated that in early cases which were not infected the use of the catheter was contraindicated He realized however that if infection were present, the situation was entirely changed Cahill (25) stated that since World War I he preferred to use the Crede method or permit overflow With this treatment he noticed a temporary rise in nonprotein nitrogen which improved after reflex bladder action returned Priestley (148) likewise advocated a non-catheter program Connors and Nash (28) reported fifty four cases (only twenty-one of which had urinary retention) treated without catheterization and maintained that there was no urinary infection in any They insisted on Crede activity every four to six hours and began the treatment before maximum distention had been reached Rupture of the bladder was not encountered and only one patient is said to have developed bed sores They admit however the occasional need for cystotomy Their paper does not

spinal cord should attain involuntary, periodic reflex voiding at satisfactory intervals and be capable of emptying the bladder

Principles of Treatment The treatment of the bladder is simple, in theory

Urinary drainage should be provided during the first and second stage of recovery or some arrangement made so that overflow incontinence will not contribute to or aggravate pressure sores over the sacral and trochanteric regions A type of drainage must be employed that will keep bladder infection at a minimum not contribute to infection of the upper urinary tract, avoid genital sepsis not interfere with ambulation and permit ultimate rehabilitation of the bladder to a voiding state

Prompt recognition of favorable changes in bladder musculature which are indicative of progress to a third stage of recovery is imperative These changes should lead to voluntary voiding in patients with partial transection and efficient reflex voiding in those with complete transection

Methods of Bladder Care Although all agree as to the objectives and principles described above opinion differs as to the best method by which to accomplish these aims

Non-drainage program Over a period of years there have been a number of authors who have advocated a strict non-drainage program The bladder is thus permitted to distend and overflow or manual expression of urine is accomplished by abdominal massage of the organ every four to six hours By refraining from the use of a catheter it has been hoped that urinary infection might be avoided Temporary distention of the bladder for a matter of hours is not harmful and does not interfere with the recovery process Long continued distention of the bladder is harmful and interferes with resumption of function

not been done previously and if the urine is not infected 2 When infection is present this form of treatment must be abandoned immediately Opinions differ as to the frequency of the development of urinary infection during a non catheter program

The non-catheter program may prove satisfactory in individual cases when adequate personnel can skillfully empty the bladder by the Crede method and maintain a dry bed, but where a number of cases are to be cared for at one time or transportation is involved it is very doubtful if such a program will either be safe for the patient in avoiding bed sores or best for the bladder should urinary infection develop In recent years there appears to have been a trend away from this type of treatment Results obtained by other methods during the recent war have not been a cause for regret nor have they led to renewed enthusiasm for a non catheter program

Intermittent catheter drainage In the treatment of spinal cord injuries the intermittent catheter drainage program is the worst type of treatment that can be adopted During World War I certain English installations used it as the universal treatment for the bladder in cases of spinal cord injury Thomson Walker s (184) report of this tragic experience should forever prohibit the adoption of this type of program In his series the estimated total death rate due to urinary sepsis was 80 per cent During 1915 and 1916 Thomson Walker saw 339 cases which arrived at the King George Military Hospital two to three weeks after injury Over 47 per cent were dead within eight weeks Of those who survived and were later transferred to another hospital 17 per cent died of urinary infection

Intermittent catheterization for longer than 72 hours always leads to urinary infection and it is now a well estab-

mention the ultimate state of bladder function Wesson (194) also favored a non-catheter program and appeared overly optimistic when stating that they will all overflow and be converted into automatic bladders within ninety six hours. There are no quoted series of cases in his paper for detailed information on this form of treatment. Munger (115) advocated a non-catheter program in those who had not been previously catheterized but he believed all infected cases should have suprapubic drainage. Hinman (74 75 76) likewise favored a trial at manual expression of urine as the best method for the early development of an automatic bladder when it works and also the best method to avoid urinary infection Manual massage of the bladder from above downward toward the symphysis by the palm of the hand must be performed every four hours by the clock. This method he acknowledged to be time consuming and to require conscientious personnel and it is applicable only when there is no urinary infection and no mechanical obstruction Brock (20) however believed that the tendency to infection on the chronically over-distended bladder was nearly as great as when catheterization and bladder irrigations were used Riches had only partial success with manual expression of urine and concluded it was neither safe nor certain for routine use

A number of the earlier recorded proponents of this form of treatment apparently advocated it because of the poor results with a program of intermittent catheterization. It is unfortunate that there is no sizable recorded series describing the ultimate type of bladder function and the extent of rehabilitation with this form of treatment

The opinions just quoted appear to agree that 1 It is possible and sometimes preferable to treat the bladder by periodic manual expression of urine if catheterization has

(Robinson) soft rubber catheter or the balloon (Foley) catheter may be chosen The balloon catheter with a 5 cc bag requires less daily adjustment and avoids the possible penile constrictions and abrasions of adhesive tape Cystoscopic observations in patients have convinced us that there is no bladder neck edema or necrosis caused by the distended bag of the balloon catheter Furthermore it is the only type of catheter that can be kept properly adjusted when priapism is recurrent There is seldom intravesical enlargement of the prostate in young males so the balloon type catheter remains in satisfactory draining position in the bladder The Robinson catheter can be used effectively if proper application of penile adhesive is maintained It has a slightly larger internal diameter in corresponding sizes than the balloon type

The catheter and the rest of the drainage system require daily attention Even though there is no evidence of encrustation the catheter should be changed with sterile technique every seven to ten days

In order to keep bladder infection minimal bladder irrigations are required in addition to a high urinary output Irrigations can be accomplished by syringe a closed system with manual control or a closed system with automatic control (tidal drainage)

Syringe irrigation is effective and occasionally necessary if the catheter becomes blocked by debris or clot Facilities for this method should always be at hand For routine use however it requires sterile utensils for each irrigation with each patient, an exacting load in time and effort for the nursing personnel Moreover there is a chance for cross contamination from bed to bed when each catheter must be disconnected and reconnected at each treatment This type of irrigation is not recommended for routine use

lished urological principle that this type of drainage should never be used over a period of more than a few days

Constant drainage In an effort to avoid over-distention of the bladder as well as severe infection in the bladder which resulted from intermittent catheterization, Kidd (82) advocated drainage of the bladder with a "tied in catheter" a form of therapy which has now been used in urological cases for many years

The main objection to drainage of the bladder by a urethral catheter is the possible occurrence of urethral or scrotal sepsis Periurethral abscess with fistula formation at the penoscrotal junction is a serious complication in the paraplegic patient The opening is slow to heal and may require plastic surgery When voiding is re-established and the ordinary glass or metal urinal is used, it is often difficult to prevent leakage of urine from the fistula into the bed or clothing For this reason complete rehabilitation of the bladder may be delayed for weeks by the urethral fistula. Scrotal sepsis although a definite complication which may result in loss of part of the scrotal contents is not dangerous to life or likely to delay recovery materially if treated properly

The main advantage to drainage of the bladder by urethral catheter is the avoidance of surgery (cystotomy or urethrostomy) and the time saved during healing of a surgical wound

Expert care with close attention to gentleness and sterile technique will pay high dividends Crude handling of the catheter will take its toll in complications The catheter used must never be larger than 18F The urethra of the paralyzed patient has no more tolerance to pressure than the sacral or trochanteric regions

For urethral catheter drainage either the two holed

(Robinson) soft rubber catheter or the balloon (Foley) catheter may be chosen The balloon catheter with a 5 cc bag requires less daily adjustment and avoids the possible penile constrictions and abrasions of adhesive tape Cystoscopic observations in patients have convinced us that there is no bladder neck edema or necrosis caused by the distended bag of the balloon catheter Furthermore it is the only type of catheter that can be kept properly adjusted when priapism is recurrent There is seldom intravesical enlargement of the prostate in young males so the balloon type catheter remains in satisfactory draining position in the bladder The Robinson catheter can be used effectively if proper application of penile adhesive is maintained It has a slightly larger internal diameter in corresponding sizes than the balloon type

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Closed system manually controlled type of irrigation has been commonly used in routine urological work for a number of years Nesbit and Gordon (129) have employed the method in patients with spinal cord injuries We used a similar apparatus during military service with great satisfaction (Fig 23)

The unit can be easily sterilized in the autoclave and kept ready for immediate use in sterile packs It is simple to set up and quickly disassembled for re-sterilization Attendant personnel can irrigate the bladder easily quickly and without chance of contamination as long as the irrigating fluid is sterile Setting up the unit takes no longer than connecting the ordinary drainage tube and over a long period

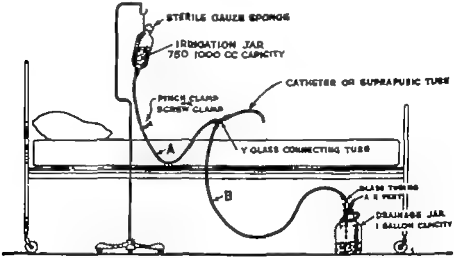

FIG. 23 Diagram for closed system of drainage and irrigation of the bladder manually controlled. To irrigate bladder open clamp on A while B is pinched off After the proper volume has entered the bladder pinch off A and release B Repeat this maneuver several times, then reapply clamp on A.

(From Prather *J Urol* 57 20 1947 *TB Med* 162 Surg. General s Office, U S Army and Prather *Preoperative and Postoperative Treatment* — Mason and Zintel, W B Saunders Co 1946, pg 501)

the net saving of time and effort is considerable Irrigations can be forceful (by gravity) so that the bladder is cleansed thoroughly at each irrigation

The patient may soon learn to irrigate himself a definite number of times per day as well as others can The individual amount for each bladder fill is easily seen on the calibrated irrigating jar so that with instruction each patient can run his own unit (except cervical cord injuries with paralysis of arms)

With this system there is no difficulty with failure of drainage by air in the tubing and no difficulty of renewal of drainage after a period of ambulation We believe this system is simple effective and compatible with optimum functional activity of the bladder

Closed system, automatically controlled, (tidal drainage) provides a closed system of drainage and irrigation of the bladder in which periodic irrigation and emptying occurs automatically Laver (93) first described an automatic irrigator (Fig 24) which he believed was based on two principles 1 Water finds its own level and 2 Siphon Munro and Hahn (116) announced the use of a more complicated apparatus for the same purpose in 1935 and dubbed it tidal drainage Munro has championed this type of bladder drainage and irrigation since that time More recently Cone and Bridgers (27) Lawrie and Nathan (94) and Stewart (175) and Bellis (10) have described simplified models which are effective and permit cystometric studies without further apparatus Illustrations of apparatus along principles advocated by Stewart, and Cone and Bridgers are shown in Figures 25 and 26 All of the various models aim to provide automatic filling and emptying of the bladder at a predetermined level of intravesical pressure To be used intelligently

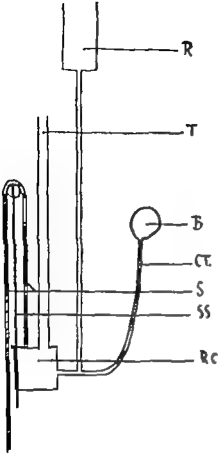

FIG 24 Diagram of early automatic bladder irrigator
RC—A watertight receiving chamber with three openings
R—Container for irrigating fluid placed above the apparatus
B—Bladder
CT—Catheter tied into bladder
T—Glass tube known as the tower
SS—Rubber siphon tube
S—Stand — adjustable for height
(From Laver *Guys Hosp Gaz.* 31:72 1917)

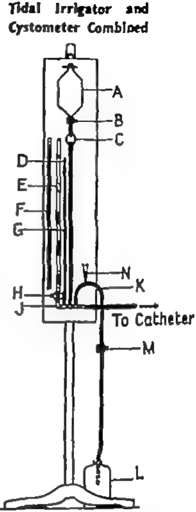

FIG. 25 Stewart s model of tidal irrigator and cystometer as modified from model by Bellis. The proper diameter of air vent in tube D can be more easily accomplished by using ¼ in. glass tubing with 23 gauge needle connected to upper end of tube D by means of rubber tubing
(From Stewart, *Lancet* 1 288 1942)

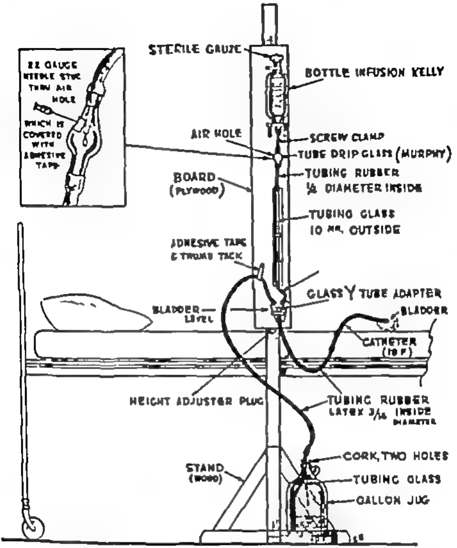

FIG 26 Diagram of apparatus for automatically controlled bladder irrigation (tidal drainage) after the principle of Cone and Bridgers A wooden stand on casters holds the infusion bottle and tubing The air vent must not be larger than the diameter of a 22 or 23 gauge needle. If a closed Murphy drip bulb is used the air vent needle can be inserted through rubber tubing just below the drip bulb (From *TB Med* 162 Surg General s Office, U S Army Prather *J of Urol* 57 21 1947 and Prather *Preoperative and Postoperative Treatment*—Mason and Zintel W B Saunders Co 1946 pg 524)

previous cystometric studies are necessary so that the level of the siphon loop may be properly adjusted

The system will not function properly if there is air in the rubber tubing leading to the bladder nor will the emptying of the bladder be effective if the opening of the air vent is larger than a 22 gauge needle.

The solution used for an irrigating medium in either the automatic or manually controlled system should be sterile, antiseptic if possible, non irritating and preferably of such quality as to delay or prevent phosphatic deposit on glass and rubber tubing Sterile water saline, boric acid potassium permanganate sulfanilamide, and solutions G and M of Suby and Albright (177) are among the many which have been tried with varying success

We found solution G too irritating for long continued use in the bladder as manifested by bloody mucus in the irrigating returns

Solution M, whose formula is hereby quoted,

Citric acid (Monohydrous)	32 35
Magnesium oxide (Anhydrous)	3 84
Sodium carbonate (Anhydrous)	8 84
Distilled water q.s ad	1000 00

can be autoclaved and did not produce these undesirable features and proved more effective than boric in delaying encrustations on tubing but the ingredients of the formula are not always immediately available in the large quantities often necessary Boric acid can be used as the irrigating fluid with satisfaction

It is desirable to have a distinctive coloring for the irrigating solution so that no error or substitution can be made by personnel when filling the irrigating jar A small quantity of methylene blue will suffice for this

The advantages of tidal drainage have been discussed by

Stewart (175) who believes that besides controlling infection it reduces the difficulties of nursing and medical care Wells (192) was greatly impressed by this method during the early part of this war Kerr (81) and Nissen (134) preferred treatment by tidal drainage where facilities and trained personnel were available Riches stated that the time required for the development of a reflex bladder was slightly less when this form of treatment was used Hinman (75) proposes tidal drainage in civilian cases when treatment by manual expression of urine can not be done or is contraindicated, and believes it hastens the development of an automatic bladder provided detailed attention is given to the care of the catheter and the apparatus Munro (125) urges the early use of tidal drainage to avoid urinary infection When this method was not used from the start, he found 20 per cent still showing urinary infection at time of discharge from hospital in comparison to 8 per cent of those treated by tidal methods from the beginning The same author reported an earlier study of final results to show urinary infection in 73 per cent not treated by tidal irrigation as contrasted to 15 per cent in whom this treatment was used (118)

The disadvantages of tidal drainage include those common to all methods which employed urethral catheters over a long period of time namely possible urethral and scrotal sepsis Munro reported complications in the bladder urethra and genital organs in 19 per cent of those in whom tidal drainage had been used from the time of injury in comparison to 26 per cent in a series before this form of treatment was begun A few minor objections may be peculiar to the apparatus itself Lewis (100) found that the bladder was not always emptied, due either to change in position of the patient or air trapping Both he and Thomas (181) feel that

previous cystometric studies are necessary so that the level of the siphon loop may be properly adjusted.

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The advantages of tidal drainage have been discussed by

comprehensive reports of Thomson Walker and Riches in addition to our own experiences during the recent war all indicate that cystotomy presents no difficulty in the rehabilitation of the bladder to a voiding state Only occasionally is secondary closure of the suprapubic sinus necessary Functional results and bladder capacity are not influenced unfavorably even after months of drainage provided bladder infection remains minimal

The suprapubic tube can be connected to a closed system of drainage and irrigation manually controlled to avoid possible cross contamination by personnel using syringe irrigations and with the closed system patients often learn to irrigate themselves efficiently a number of times each day Cystometric determinations can be done via the suprapubic tube if the cystotomy has been performed properly

Suprapubic drainage does not interfere with ambulation or frequent changes of position in bed although it is troublesome if a Stryker frame is to be used over a long period

The disadvantages of suprapubic drainage are that it is a surgical procedure and that it will take three to four weeks for the sinus to heal during a period of urethral catheter drainage when rehabilitation of the bladder is at hand In addition, a small suprapubic dressing is advisable Munro (125) has stated that the tube is prone to rot and break that it fails to prevent puddling and that it promotes shrinkage and fibrosis of the bladder wall Like urethral catheters the suprapubic tube requires changing periodically but our own studies definitely refute the assertion that this form of bladder drainage leads to shrinkage of bladder capacity

Lewis (98) has objected to suprapubic cystotomy unless it is certain that a long period of drainage is necessary because of leakage of urine around the catheter We have not

a thorough bladder irrigation should be used each day Bumpus Nourse and Thompson (22) who used tidal drainage in the majority of cases at some stage of convalescence during World War II found supplemental irrigations necessary to prevent puddling of infected urine and accumulation of calcium debris in the bladder This occurred in spite of their best efforts to maintain efficient automatic drainage. Morson (110) objected to tidal drainage because it confined the patient to bed

After personal experience with war casualties treated by all of the various methods of drainage and irrigation listed in this text we have the firm conviction that tidal drainage is an excellent method of providing drainage and irrigation of the bladder but that it is not essential for the optimum recovery or rehabilitation of the paralyzed bladder

Suprapubic cystotomy Suprapubic drainage of urine during paralysis of the bladder has been advocated by a number of urologists in an attempt to avoid urethral sepsis and to protect the upper urinary tract against sepsis During the first world war Thomson-Walker (183) made a plea for this type of program, and twenty years later still favored cystotomy whenever Crede methods failed. Boyd and Bailey (19) believed suprapubic cystotomy was the logical method of treatment, and Munger (115) favored this drainage whenever urinary infection was present. Hinman (75) suggests cystotomy when previously mentioned methods of treatment appear to have failed in civilian cases and advocates its immediate use in war conditions if the spinal cord injury is severe Riches (152, 153) has advocated suprapubic drainage at an early stage in the hope of preventing renal infection, although he realized that there was no influence on renal sepsis which was already established. The

a Malecot tube to the bladder to drain the paralyzed bladder Although we have not used the procedure the following objections should be considered While the suggested placement of the tube avoids periurethral abscess and fistula at the penoscrotal angle the possibility of prostatic and scrotal sepsis is not diminished Of necessity the incision and channel for the tube is in close proximity to an incontinent anus and offers undue chance for urinary infection The bad effect of pressure of the tube on perineal structures when in a sitting position also might delay wheelchair ambulation Should there be delay in healing of the urethrostomy opening prolonged urethral catheter drainage would be required because the buttocks would be wet on each voiding The above considerations would seem to rule out this type of drainage for routine use unless a series of cases demonstrates that the above objections are not valid

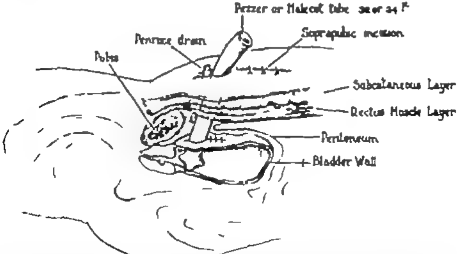

FIG. 28 Wrong placement of suprapubic tube causing pressure on trigone with perhaps edema around ureteral orifices With the tube in this position it is difficult to obtain further surgical exposure of the bladder without opening the peritoneum Following removal of the suprapubic tube the sinus is short and may require a longer period to heal than when there is an oblique sinus

(From Prather *Bull U.S Army Med Dept* 81 97 1944)

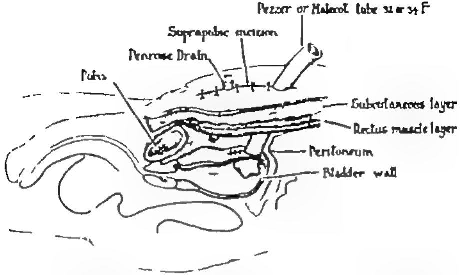

FIG. 27 Correct placement of suprapubic tube high in vertex of bladder This avoids pressure on trigone permits easy surgical reentry into the bladder and creates an oblique sinus when this tube is removed
(From Prather *Bull U S Army Med Dept* 81-97 1944)

found leakage common when the cystotomy was properly performed the tube properly placed and daily care maintained

The technique of cystotomy deserves mention Riches (152) Prather (143) and Hamm (63) have emphasized the advisability of placing the tube high in the dome of the bladder (Figs 27 and 28) It should also emerge from the upper end of the skin incision These precautions prevent the riding of the proximal end of the tube on the trigone and urethral orifices and produces an oblique sinus to facilitate closure at a later date This technique also avoids the possibility of infection of the pubic bone which might occur if the tube were placed at the lower end of the incision adjacent to the pubis

Perineal urethrostomy A few years ago Lewis (99) suggested urethrostomy in the bulbous urethra with insertion of

function following low spinal lesions (cauda equina) are the most responsive to transurethral resection They have advised resection of small amounts of tissue from the entire circumference of the bladder neck, the total weight of removed tissue rarely exceeding 10 grams Even after operation patients with low lesions sometimes find it necessary to strain in order to empty the bladder The above authors found the results of bladder neck resection less spectacular but still worthwhile in a number of patients with automatic reflex voiding but in whom there was still an appreciable residual after urination

Baker Carney and DeRosa (1) found resection of the bladder neck useful in attempting to restore proper bladder function in elderly and debilitated patients with neurogenic disease of the bladder

Stone (176) reported no histological evidence of hypertrophy in muscular tissue removed from the bladder neck, but rightly observed that this region may cause obstruction because of spasm or rigidity He also described the tendency of paraplegic patients to bleed rather profusely during surgery either during open operation or with transurethral procedures Stone recognized justification for the operation despite a rather high morbidity rate Likewise Talbot (179) from his wide experience with veterans of World War II stated that resection is justified whenever there is persistent residual urine associated with what appears to be sufficient detrusor force as demonstrated cystometrically

Emmett (46) has written many papers expounding the benefits of bladder neck resection in the neurogenic bladder Recently Emmett Albers and Anderson (47) reviewed their collected clinical material and stated that a disturbance of the urinary sphincters is probably the greatest single factor

Cystoscopic procedures. Two types of cystoscopic procedures have proved useful on occasion for the proper care of the bladder. All instrumentation is potentially dangerous and it is to be entrusted only to skilled hands. This is especially true in the paralyzed patient.

Cystoscopic removal of bladder calculi, when they exist, is required before satisfactory rehabilitation can be accomplished. Many small stones can be removed through the sheath of the cystoscope or resectoscope with the aid of the Ellik evacuator. Larger calculi have to be crushed and fragments removed by irrigation. The above maneuvers can be done through the cystotomy wound, if present, or through the urethra. If the patient has suprapubic drainage it is best to inspect the bladder for calculi before changing to a urethral catheter program. The opening above may be useful for the removal of calculi.

Resection of the bladder neck has been employed in paraplegic patients to facilitate proper emptying of the bladder. For an eventual satisfactory functional result reflex activity of bladder musculature must be present, and sufficient sphincteric or urethral resistance must remain to avoid continuous incontinence. In many instances a well defined widening or relaxation of the bladder neck is revealed by urethrographic and cystoscopic examination. In most cases (in our experience) the desired end result of functional control and efficient emptying can be obtained without revision of the bladder neck. There are, however, instances of inefficient emptying of the bladder in which adequate reflex activity can be demonstrated cystometrically. In this latter group of cases resection of the bladder neck may prove vital in the restoration of satisfactory bladder activity.

Bumpus, Nourse and Thompson state that as the result of their experience in the Navy during World War II dys-

sphincter to relax must be corrected to achieve satisfactory bladder function Ney and Duff (132) likewise reported that spasticity of the external sphincter was not unusual By cystourethrography they found opaque dye held up in the region of the external sphincter in postvoiding films

At times spasm of the external sphincter may be demonstrated or suspected in the urethrogram Difficulty in passing a catheter through the external sphincter may give a clue Sphincterometric study may also prove helpful Careful urethroscopy can be valuable to the trained examiner in determining the state of the external sphincter

Bors (16) *reported 46 per cent good results from using* bilateral pudendal nerve block in 56 cases He incidentally found the bladder neck open after this procedure and speculated as to why this should be so Perhaps there are striated muscle fibers as high as the bladder neck which become affected by the block Perhaps there are autonomic fibers in the pudendal trunk which cease to be influential after the nerve block

Rilling (157) has reported ischio-anal abscess after pudendal nerve block in obstetrical cases the symptoms appearing six days after injection in several cases

Ney and Duff noticed *relaxation* of the external sphincter in 8 of 20 cases by urethrographic study in patients with spinal cord injury This was found in both the spastic and flaccid cases and was apparently not related to the level of the cord lesion

They noted that in general these patients had very small bladder residuals

Block of sacral nerves can be accomplished by direct injection or by spinal anesthesia permanently by subarachnoid alcohol injection or rhizotomy The principal effect is to abolish impulses over parasympathetic nerves thus eliminat

in neurogenic vesical dysfunction Residual urine is of course the foremost problem — in fact they found that 88 per cent of their cases had more than 100 cc residual Following transurethral resection they report good results in 80 per cent of 79 incomplete spinal cord lesions and 40 per cent of 35 complete lesions An additional number were reported as improved The same authors believed that the level of the lesion was not significant and found their best results in cases with a minimal amount of reflex bladder activity who could initiate urination by straining Their poorest results appeared to be in patients with an automatic reflex type of bladder

Although further experiences may alter the general opinion in regard to the role of bladder neck resection in spinal cord injuries Bors (14) has probably summarized the relative need for the operation by saying that it will be indicated in about 5 per cent of patients The procedure can be helpful in restoring satisfactory voiding in some paraplegic patients whose natural progress has not been complete

Neurological procedures to aid bladder function Although the urologist may be able to restore the anatomical features of the bladder and bladder neck to as near normal as possible there still may be gross dysfunction which can possibly be improved by the blocking of nerves

Pudendal nerve block has recently received more attention as a possible means of facilitating bladder emptying in patients who show no obstructive tissue at the bladder neck and who have sufficient detrusor power Spasm or involuntary contraction of the external sphincter can impede the flow of urine just as effectively as rigidity at the bladder neck

Emmett, Daut and Dunn (45) by urethrographic study concluded that spasticity or the inability of the external

act as parasympathetic stimulants in the bladder with a normal nerve supply Ney and Horowitz (133) described fever probably of pyelonephritic origin following the use of Furmethide in two patients with spinal cord injury who were known to have bladder residuals and ureterovesical reflux

There is very little significant data about the influence of drugs on the neurogenic bladder Drugs do not appear to have significant practical action on the paraplegic bladder either by stimulating reflex detrusor action or by causing relaxation of hypertonic muscles

Bladder training for paraplegic patients with complete transection after reflex bladder action has become re-established was recently discussed by Munro By clamping off the urethral catheter for intervals of one and one half to three hours it is hoped that the bladder will accommodate itself to a time schedule to permit the patient to void at regular intervals When this has been accomplished the patient is then given a trial on a similar schedule without the catheter

COMPARISON OF METHODS

It is difficult to compare the effects of some of the methods described above for the calibre of the personnel appears as important as the method if not more important Any method in the hands of unskilled individuals is apt to end in disaster Several of the methods in expert hands can produce gratifying results

When describing a method of treatment we assume perfect technique in skilled hands experience with the method availability of equipment and knowledge of potential complications. In time of war when treatment must often be started before a hospital for definitive care is reached and when problems of transportation are encountered these ideal conditions are unattainable Furthermore it is often difficult

ing all major detrusor activity In the words of Sheldon and Bors (168) these procedures convert an upper neuron bladder into a lower neuron bladder Dramatic changes may therefore be expected in the spastic or hypertonic reflex bladder of small capacity

Heimburger Freeman and Wilde (70) found that temporary relaxation of the detrusor was accomplished by blocking S —2 S —3 or both They also reported that the most efficient relaxation of the bladder neck was accomplished by block of S —2

Bors Comarr and Moulton (16) found that spinal anesthesia eliminated reflex contractions of the detrusor and voiding contractions disappeared Sixty-one per cent were reported as temporary good results Following subarachnoid alcohol injection small bladders and spastic detrusors improved and led to good permanent results in 62 per cent Reflex contractions became absent immediately reappeared after an unpredictable interval but were then insufficient for complete reflex voiding

The action of drugs on reflex activity of the bladder after spinal cord injury has perhaps not been fully exploited to date Nesbit and Gordon (129) found that efforts to influence either sympathetic or parasympathetic activity produced no clinical benefit Riches reported that drugs of the acetylcholine type had no favorable influence on the bladder during spinal shock, but appeared to enhance reflex contractions once recovery had set in Our own observations were confined to the use of atropine in an effort to lengthen the intervals between voidings in those with a reflex automatic type of bladder after complete transection No accurate data were kept but there appeared to be some benefit in ambulatory patients

As previously stated Urecholine ® and Furmethide ®

Drainage by urethral catheter is an accepted program but must be supplemented by bladder irrigations under sterile precautions with a closed system either automatically or manually controlled Careful hygienic attention to the catheter and urethra are required and a properly working irrigating system is essential Urethral and scrotal sepsis are potential complications The choice between manually controlled irrigation and tidal irrigation is open and depends upon the availability of equipment and training of the personnel Rehabilitation of the bladder to a voiding state should be probable

Suprapubic drainage with a properly placed tube is an accepted program perhaps preferable if a long period of bladder drainage appears necessary or if transportation problems make the urethral catheter program difficult A closed system of irrigation is advisable Periodic change of the tube is mandatory This method avoids a certain number of genital complications but eventually requires a period of urethral drainage during closure of the suprapubic sinus Rehabilitation of the bladder to a voiding state should be probable but requires a slightly longer time than the urethral catheter program

Removal of bladder calculi when present will be necessary for proper bladder function regardless of the type of drainage employed

In the later stages of recovery it may be necessary to employ urological or neurological procedures in order to attain an efficient and socially acceptable bladder in some cases

For the bladder with a large residual one must study the two regions most commonly the cause of obstruction namely the bladder neck and the external sphincter Trans

to compare effectiveness of methods except on a mass basis, and even then several methods may have been employed in an individual patient.

Except in time of war few individuals have experience with a large series of cases Those who do usually have one method of treatment which they believe the best. They therefore report the results of one method instead of a comparative study of results of different methods with the same skilled personnel It appears obvious that neurosurgeons not trained in urological surgery would prefer a method not involving detailed urological procedures if they do not appear necessary Although neurosurgeons and principally Munro have contributed more to the rehabilitation of the bladder in civilian life than urologists it will probably remain for the urologist with his various diagnostic and therapeutic procedures to make valid and conclusive comparisons of methods of treatment. The opportunity however is open only to the urologist who is interested ingenious and skilled and who has access to an appreciable number of cases.

After a review of a number of reports on the treatment of the bladder after spinal cord injury observations of patients treated by others with various methods and personal experience with the care of a series of cases during the recent war the following statements can be made.

A program of intermittent catheterization is certain to lead to disaster

A non-drainage program with overflow voiding or Crede emptying of the bladder may be used in the individual case unless there is evidence of urinary infection With this program it is difficult to maintain a dry bed and avoid decubitus ulcers. It is not a feasible program when a number of patients are to be cared for or when attendant personnel is limited. Eventual rehabilitation of the bladder is possible.

text, White and Smithwick (195) quote Carrel and Guthrie who proved that the totally denervated kidney could carry on all the renal function essential to life, Marshall and Kolls who found only a temporary increase in urine secretion following renal denervation Rhoads VanSlyke Hiller and Alving who found no consistent effect on either excretory efficiency of the kidney or on renal blood flow after denervation of the organ and Page and Neuer who could not demonstrate any change in urea clearance values or in urinary volume following renal sympathectomy

Innervation of the ureter and the function of the nerves to this organ cannot be described clearly Gruber has stated that experiments have been confusing but it must be *assumed*

FIG 29a

FIG. 29b

FIG. 29a. Routine intravenous urogram after a number of months of suprapubic drainage There is no dilation of the upper urinary tract.

FIG. 29b Further intravenous urogram several months after automatic reflex bladder action had become established The upper urinary tract remains in excellent condition.

urethral resection should correct the former and pudendal nerve block should improve spasm in the latter region. Estimate of detrusor activity by cystometric study is necessary to evaluate the reflex emptying power of the bladder

For the bladder of small capacity presumably caused by hypertonicity and excessive reflex activity one can consider the use of sacral nerve block to counteract parasympathetic activity It is necessary to realize that any procedure which abolishes all parasympathetic impulses via the sacral nerves will necessarily eliminate all significant reflex detrusor activity

Certainly no one should consider the corrective measures just described and which often involve irreversible changes until all concerned in the problem are agreed that maximum normal improvement has been attained

CHANGES IN UPPER URINARY TRACT AFTER SPINAL CORD INJURY

Detailed discussion of the anatomy and physiology of the kidney and ureter will not be presented here Our interest is confined to what little is known about the innervation of these organs and the effect of spinal cord injury on them

Innervation of the kidney according to Gruber (62) consists of both sympathetic and parasympathetic nerves but the function of the parasympathetics has not been proved satisfactorily either by physiological or pharmacological investigators He believes the sympathetic fibres contain both vasoconstrictor and vasodilator elements and that the vasomotor changes induced by the action of these fibres suffice to explain changes in the rate of secretion of urine. In their

from the ureteral orifices in jets He found normal movement of the lips of the ureteral orifices and no incompetence of the valve like mechanism With small catheters in the lower ureters Fullerton then distended the bladder to a pressure of 91 cm water to find no evidence of reflux beyond the ureterovesical junction

Plaggemeyer (139) also found that the ureteral orifices were normal in appearance in eleven cases that he studied Cumming (32) (33) found no evidence of ureteral reflux in several cases during cystography and later concluded that atony of the ureter is not common in those with bladder paralysis and that there is no tendency toward hydronephrosis

Personal observations of intravenous urograms and cystograms in many patients during the recent war confirm the above observations (Figs 29 to 31 illustrate intravenous urograms in paraplegic patients) Unless there is basic obstructive pathology independent of the bladder dysfunction, the intravenous urograms are normal and in only the rare case can one observe reflux in the cystogram When reflux does occur it is probably due to a localized change of the ureteral orifice by inflammation edema and so forth rather than to a physiological change caused by the spinal injury itself

Talbot and Bunts (179) observed a series of 331 patients over a period of two years and discovered that 5 per cent showed a hydronephrosis which was not associated with calculus disease or evident obstructive factors In this group of hydronephrotic cases two-thirds showed evidence of vesico-ureteral reflux

In a separate study Talbot and Lyons (180) reported on the late renal changes in 182 paraplegic patients in whom

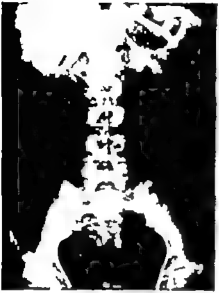

Fig 30

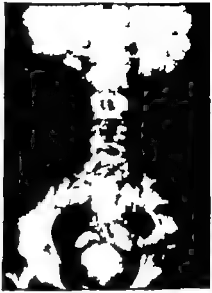

Fig. 31

Fig. 30 Routine intravenous urogram in patient with complete transection of the upper dorsal portion of the spinal cord Bladder had been on suprapubic and urethral catheter drainage with closed system of irrigation manually controlled for over a year

Fig 31 Intravenous urogram after voluntary voiding had become reestablished in patient with partial transection of the cauda equina.

that the ureters are innervated by inhibitory and motor sympathetic fibres and motor fibres from the parasympathetic. White and Smithwick have indicated that ureteral nerves are known to carry afferent impulses but serve no known motor function

After injury of the spinal cord there appears to be no anatomical or physiological change in the ureters either directly attributable to the injured nerve tissue or to the immediate altered bladder physiology

Fullerton s (52) notable cystoscopic observations in patients with gunshot wounds of the spine demonstrated that ureteral peristalsis continued and that indigocarmin appeared

pecially if bladder emptying is incomplete or inflammatory processes have permanently altered the vesicoureteral junction To properly interpret the upper urinary tract years after spinal cord injury, earlier studies on the same patient must be available for comparison

In summary, there is no immediate alteration of renal or ureteral physiology and usually no evidence of vesicoureteral reflux caused by spinal injury unless complicating factors intervene

CHANGES IN SEXUAL ORGANS AFTER SPINAL CORD INJURY

According to Mettler (109) the *chief parasympathetic nerves* to the genital organs of the male arise from the third and fourth sacral nerves to form the nerve erigens Stimuli over this route lead to penile erection by dilatation of the vessels of the corpora cavernosa Fulton also stated that secretion of prostatic fluid is increased Both Mettler and Fulton agree that in the female parasympathetic fibers enter the uterus and tubes but Fulton does not believe that nerve stimulation has any effect on the organ Vaginal secretions are however believed to be increased

Sympathetic fibres to the genital organs arrive at the pelvic plexus via the hypogastric plexus In the male stimulation of these nerves leads to ejaculation by means of contraction of the musculature of the seminal vesicles and ejaculatory ducts and contraction of the vessels of the corpora cavernosa Ejaculation can occur without erection In the female according to Fulton sympathetic stimulation produces variable effects on the uterus depending on the species and the presence or absence of pregnancy

Somatic fibres leading to the perineal muscles through the pudendal nerve aid in completing the act of ejaculation

there was a mean interval of two years between injury and the observations — only 7 2 per cent were found to have evidence of destructive renal lesions

Renal function is not usually influenced adversely by any neurogenic or back pressure effect per se in this type of injury Plaggemeyer (140) found that renal function remained the same over a two-year period in a series of thirty five cases which he studied Personal observations on kidney and ureter during the past few years confirm the studies made during World War I to again demonstrate that renal function is maintained satisfactorily unless renal infection or calculus disease complicate the condition. These statements refer to a period of two years or less and include many whose bladder has been rehabilitated to a voiding state At this time it is impossible to report the status of the upper urinary tract in a large series of cases a long time after injury but there are some indications of upper tract deterioration in cases with an autonomous bladder over a period of many months Long term follow up studies in a large series of patients is needed for these important data

Rogers and Bors (159) studied the renal function of 70 paraplegic patients They found that 47 1 per cent showed impairment of urine concentration and 5 7 per cent showed impairment of both dilution and concentration Tubular excretion was measured by the phenolsulfonphthalein test Twenty four per cent had a reduced output of the dye The non protein nitrogen level in the blood was normal in all They found no correlation between the extent of spinal cord damage and the amount of kidney dysfunction

Sporadic case reports by Hepler (73) and personal observations indicate that the long term study may reveal an increasing incidence of upper urinary tract dilatation, es

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of all other spinal cord injuries either partial or complete at any level

Talbot (178) in a study of 105 patients with the level of injury at T 11 or higher discovered that 75 per cent retained the erectile reflex In 77 patients with lesions at lower levels Talbot found that 50 per cent showed erections

Ejaculation is also a complex segmental reflex function as reported by Horne, Paull and Munro Again supraseg mental connections are not necessary Their evidence indicates that ejaculation will be prevented by a destructive lesion of the sacral segments or cauda equina and can be affected by an extensive lesion between the segments of T6 and L 3 depending on the destruction of the sympathetic components in this area of the cord In the surgery of the sympathetic system Retief (150) reported that when the second lumbar ganglion was left intact on one or both sides ejaculation was not influenced unfavorably

Fertility studies since World War II are also of interest Bors Engle Rosenquist and Holliger (17) studied 34 patients during a period of 4 to 56 months after injury Microscopic examination of testicular biopsy specimens showed changes in all but three The predominant picture was tubular atrophy with no change in Leydig s cells In general histological changes in the testis were less prominent if the cord lesion was below T 11 Time did not appear to be an important factor They found no relation between the testicular findings and sex function

In a similar study of testicular biopsies Stemmermann Weiss Auerbach and Friedman (173) examined 16 young volunteer paraplegics in good general condition The histological picture of testicular biopsies in six patients was normal Ten specimens showed good maturation arrest with varying degrees of atrophy of germinal epithelium No

Sensory nerves are believed to travel both the sympathetic and parasympathetic pathways

After injury to the spinal cord and after recovery from spinal shock reflex erection of the penis and priapism are not uncommon Ejaculation has also been described In the female, Fulton states that a normal menstrual period usually follows within five or six days of injury and recurs at normal intervals thereafter In animals pregnancy has been established and completed after the spinal cord has been severed.

In a study of twenty cases Cobb and Coleman (26) found that as a rule sexual function suffered relatively more than urinary or rectal function after cervical injuries while in lower injuries sex potency might return while there was still lack of control of urine and feces

There have been several fine publications on this subject since World War II which should be reviewed in some detail Horne Paull and Munro (79) reported that erection takes place on a purely segmental reflex basis and can be accomplished without suprasegmental connections Afferent sensory impulses that initiate the reflex are caused by tactile stimulation of the glans They travel to the second third and fourth sacral segments via the internal pudic nerve The efferent impulses leave these same segments via the parasympathetics to cause dilation of the arterioles of the penis, resulting in distention of the corpora cavernosa and spongiosum Efferent impulses from the sacral segments also leave by way of the internal pudic nerves to cause contraction of the periurethral muscles and compression of venous drainage channels of the penis

Horne Paull and Munro found that destruction of the sacral segments of the cord, cauda equina or parasympathetic plexus are the only neurologic lesions that will prevent the occurrence of erections Erections can occur in the presence

Renal Infection We shall not attempt to differentiate clearly between pyelonephritis and the so-called cortical abscesses of the kidney realizing that probably a number of cases called pyelonephritis have microscopic abscesses in the renal parenchyma It is difficult to offer proof of the exact diagnosis in clinical work except in surgical specimens or autopsy material

The mortality rate from renal infection was alarmingly high during World War I and before the era of the present urinary antiseptics Thomson Walker's (184) report on a large series in which 47 per cent died within eight weeks cannot fail to create concern for the recovery of many patients. Still others in his series died at a later date of genitourinary infection Vellacott (187) reported ten per cent deaths from urological causes during the first month after injury and it may be assumed that others succumbed later to this same malady

During the recent war intravenous urography more effective medicinal agents and better handling of the paralyzed bladder helped to reduce the toll of renal sepsis Although we have no data for the first few weeks after injury those patients who were transported back to the United States have in general done well

Raines (149) reported no deaths from urological causes in a series of over one hundred cases observed for a period of months Petroff (137) had only one death among seventy patients over a period of a year or more and Prather (142) reported only one death from urological disease in a series of sixty-one cases over a period of eighteen months

Patients who appear to have renal infection after spinal cord injury usually have the diagnosis made on the basis of fever and perhaps pain, nausea vomiting urinary findings

spermatogenic cells were present in a few while in others rare spermatids and spermatozoa were present. They reported that the material was inadequate for appraisal of the interstitial cells of Leydig No relation could be found between the presence of maturation arrest and level or duration of the spinal cord lesion sexual potency or general systemic factors

Horne, Paull and Munro (79) made fertility studies on 18 paraplegic patients by stimulating the seminal vesicles and prostate electrically and obtaining the specimen by massage of those organs They concluded that *spinal cord injury itself does not preclude fertility*

GENITO URINARY COMPLICATIONS

In patients who have survived the direct results of the injury complications may lead to demise Urinary tract complications have been prominent particularly the renal disorders which are to be discussed Even before the work of Lister thought was given to the changes in the urine of paraplegic patients Curling (35 36) believed that the alkaline condition of the urine was produced primarily by morbid secretions of the bladder and secondarily from the debilitated state of the kidneys Burne (23) likewise placed the primary complication in the bladder by finding foul ammonical urine in the bladder and acid urine in the kidneys

KIDNEY

Renal infection and calculus disease are the two serious urinary tract complications All too often they appear to exist together each aggravating the other at the expense of the host.

The *diagnosis* of renal infection is usually made after attention has been called to an abrupt rise in temperature sometimes preceded by a chill Pain is not present unless the level of anesthesia is below the level of the upper abdomen If the patient is on drainage and has been showing a mild urinary infection the urine will at times show a gross change but this is not often a reliable sign Those who are voiding a clear urine will usually develop a cloudy urine with the onset of an acute or recurrent infection

The first important question raised by a fever caused by renal infection is whether or not there is obstruction at some point in the upper urinary tract If there is no obstruction for example by calculus medicinal measures can be pushed to the limit If there is obstruction these measures will rarely be sufficient Since ureteral catheterization is not a good routine procedure in this type of case, intravenous urography is a good way of disclosing obstruction of a kidney The value of routine study periodically during the afebrile period of normal convalescence is enhanced by the ability to compare films taken later during a febrile episode Only by periodic examinations of this type can the upper urinary tract be indirectly visualized and the correct interpretation given to an episode of renal infection We have no hesitancy about using intravenous urography during the first days of a febrile reaction

Treatment of renal infections today is far more effective than it was some years ago even though complete and permanent sterilization of the urine is not always attained Because of the ever present necessity of forcing fluids to combat calculus formation and the advisability of a high fluid output in renal infection, medicinal agents which require restricted urinary output for their best effect are not useful

or exclusion of other causes The condition may of course, be acute recurrent or chronic In only the first types, acute and recurrent does the temperature chart usually give a clue

The mode of infection as in those who have not received spinal injury can be by the hematogenous lymphatic or ascending routes In those with spinal cord injury it is difficult to prove which route is most common As stated previously reflux cannot be demonstrated in the majority of cases so that it should not be assumed that the ascending intraureteral path is the principal route There are many other possibilities transmission to kidney via periureteral lymphatics from an infected bladder dissemination via the blood stream from septic foci in other parts of the body that include areas injured by penetrating missiles and bed sores, and transmission from the intestinal tract Petroff found three cases with positive blood cultures

The *types of organism* responsible for renal infection are multiple Although the organisms found in bladder urine do not necessarily mean that the same bacteria are causing the renal infection, they probably offer the best general guide that is available without ureteral catheterization or surgery Raines found Aerobacter aerogenes Escherichia coli and Bacillus proteus the most common in cases showing pure cultures of the urine In combination with the above varieties he frequently found Streptococcus NON HEMOLYTICUS Alkaligenes fecalis and Staphylococcus AUREUS Petroff found the bacilli mentioned above were more difficult to eradicate than the coccus forms Prather stated that cultural studies of urine specimens from patients on drainage usually showed a mixed infection The bacteria most frequently encountered were Pseudomonas Aeruginosa, Proteus vulgaris, Escherichia coli, Bacillus cloacae and Staphylococci

Streptomycin has proved a valuable agent for the treatment of gram negative bacilli in the urinary tract especially in relieving the virulent febrile stage which has not been controlled by the sulfonamides It can be used simultaneously with sulfonamides or with penicillin Although the optimum dose of streptomycin is not agreed upon at this writing all appear to agree that large doses at the beginning of treatment help to prevent the development of resistance by the organism With the present standard of 1 000 000 units to the gram 300,000 to 400 000 units intramuscularly every three hours appears to be the average dose For best effect five to seven consecutive days of medication appear to be necessary for a fair trial Alyea (1) has found this drug most effective in an alkaline urine

Penicillin appears to be our most effective agent against coccus infections in the kidney Customary doses are 20 000 to 40 000 units intramuscularly every three hours This drug can be used simultaneously with streptomycin or the sulfonamides if there appears to be need Penicillin is believed to be most effective in an acid urine

Occasionally ureteral catheterization drainage or lavage will be desirable in the treatment of renal infection It must be used cautiously always yet perhaps heroically on occasion to relieve obstruction to facilitate diagnosis and to prepare some patients for operation A very thorough irrigation of the bladder is desirable before ureteral catheters are passed through it on their way to the kidney

Renal calculi The combination of renal calculi and renal infection is the great enemy of recovery in those who have suffered spinal cord injury

Data accumulated during the recent World War showed a disturbingly high *incidence* of renal calculi during a period

Fortunately the use of sulfonamides penicillin and streptomycin permit a high urinary output In addition to the urinary antiseptics just mentioned and the high liquid intake and output the general nutritional state of the patient must not be overlooked Transfusions plasma amino acids and vitamins may play an important part in the treatment.

For the renal infections caused by gram negative bacilli, the sulfonamides appear to be the best for routine use except in those who have developed sensitivity to the drug Sulfadiazine or sulfonamides in one gram doses by mouth every four to six hours around the clock with an equal quantity of soda bicarbonate has been our customary treatment for the ordinary renal infection It is our feeling that larger doses are seldom more effective and that even smaller quantities may be just as useful Once begun medication should be continued for a period of five to seven days We have given one gram four times a day over a period of several weeks without untoward reaction If these drugs cannot be used by mouth sulfadiazine can be utilized intravenously Although there is probably no reason why a patient with spinal cord injury should be exempt from renal complications of the sulfonamides we are not aware of any case of anuria of this type

Simons (171) has reported a study on the use of Mandelamine for sterlization of the neurogenic bladder Most cases had significant bladder residual Mandelamine was used in a quantity of 3 to 4 grams a day and for at least 45 days Cure was reported in 52 9 per cent of 68 cases

The current antibiotics chloromycetin aureomycin and terramycin have proved effective in bacillary infections of the urinary tract and can be of use when patients are allergic to or resistant to the sulfonamides

Bowie (18) reported 18.6 per cent, Riba (131) 13 per cent and Malcolm (103) 9 per cent

The frequent occurrence of renal calculi in the recumbent patient is a well established phenomenon Flocks (51) has stressed the three known *etiological factors* namely, infection stasis and hypercalciuria

Patients with injury of the spinal cord are commonly confined to bed for a period of weeks or longer until stability of bony structures permit ambulation It is not surprising then to find a high incidence of stone in this group

Routine intravenous urograms in a series of sixty cases (Prather) many of whom had been bedfast and on bladder drainage for many months, showed no dilatation of kidney pelves or ureters Similar studies several months later when voiding had been re-established likewise revealed no upper urinary tract dilatation It is probable that calculus formation is not due to any gross anatomical change that can be demonstrated by pyelographic study

Calculi can form rather quickly Large stones have been found to develop in a period of five months, and it is not unusual to see a definite increase in size during an interval of two months Bilateral stone formation was common, but no more so than the unilateral distribution Illustrations of urinary tract calculi in paraplegic patients are shown in Figs 32 to 38

Symptoms are lacking in those with transection in the upper part of the spinal cord Even patients with a level of anesthesia below the kidney area seemed to have less pain than the non paralyzed patient Gross hematuria occurred occasionally but has been seen more often in orthopedic patients confined to bed than in the paraplegic patient Nausea and vomiting were common symptoms often thought

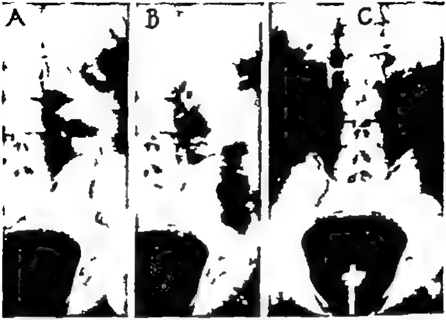

FIG. 32a. Two left renal calculi in paraplegic patient with high fever. At time of operation the left kidney was septic and contained multiple cortical abscesses. Left pyelolithotomy was done rather than nephrectomy because of calculus in upper pole of opposite kidney. Patient made excellent recovery from operation.

(From Prather. *J. Urol.* — in press.)

FIG. 32b. Intravenous pyelogram showing calculi in kidney.

FIG. 32c. Postoperative intravenous urogram following surgical removal of left renal calculi from severely septic kidney. The kidney has excellent function.

(From Prather. *J. Urol.* — in press.)

of approximately fifteen months after injury. Prather employed routine intravenous urography at intervals of 6 to 8 weeks and demonstrated renal calculi in 31.5 per cent of those with complete transection, and in 20 per cent of those with partial transection. Other authors who did not differentiate between complete and incomplete lesions also reported a high incidence. Petroff's figures were 20 per cent,

Stasis in the kidneys must be combated by change of body position every two hours. This can be accomplished without a Stryker frame. A forced fluid program also helps to avoid urinary stasis in renal calyces and pelves.

At the present time hypercalciuria is difficult to combat

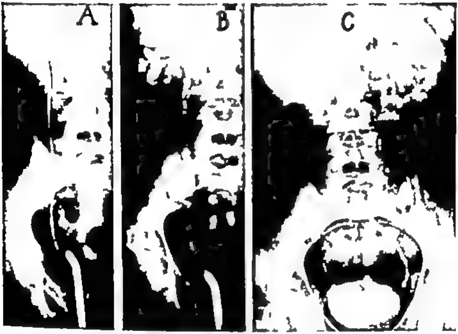

FIG. 34a. Right ureteral calculus at level of lower border of sacroiliac joint in patient with complete spinal cord transection in mid-dorsal region.

(From Prather. *J Urol* — in press.)

FIG. 34b. Retrograde pyelogram shows abnormal kidney and ureter above the obstructing ureteral stone. The numerous filling defects were caused by inspissated pus. Right ureterolithotomy was done with prompt recovery.

(From Prather. *J Urol* — in press.)

FIG. 34c. Postoperative intravenous urogram following right ureterolithotomy demonstrating excellent anatomical and functional recovery by right kidney.

(From Prather. *J Urol* — in press.)

to be due to dietary upset until the correct diagnosis was established

Accurate *diagnosis* can only be established by x ray Intravenous pyelography is to be preferred to retrograde study as a routine measure It is imperative to determine the degree of obstruction caused by the stone if proper treatment is to be given. At times retrograde examination is necessary to make the diagnosis but this should be done only after painstaking irrigation of the bladder to prevent introduction of organisms to a clean field or new organisms to a locale which is already infected Stereoscopic and oblique films often aid in the localization of opaque shadows and at times are necessary to avoid mistakes in interpretation.

FIG 33 A small calculus in upper right ureter completely obstructs the right kidney as shown in the intravenous urogram. In addition there is a small stone in the right kidney Both calculi were removed surgically at the same operation.
(From Prather *J Urol* — in press.)

Treatment should first be directed against the known causative factors The incidence of renal infection can be reduced by proper treatment of the bladder by improved general condition and by expert attention to foci in other parts of the body particularly pressure sores A routine daily liquid intake of 4000 cc is an aid in the prevention of renal infection

wait until the patient is ambulatory before undertaking operative removal Calyceal stones do not warrant surgery Occasionally, however, calculi will obstruct the kidney of a bedfast patient and operation will be necessary if the patient is to survive The most efficient urinary antiseptics are not adequate to control infection under these circumstances

In the ambulatory patient surgery may be planned and a time elected hoping to remove all calculi before they be

FIG 37a Two large calculi completely obstructing the right kidney of a paraplegic patient that are known to have formed in five months They were removed surgically

(From Prather *J Urol* — in press)

FIG 37b Postoperative intravenous urogram showing good functional and anatomical recovery of right kidney following removal of two large calculi

(From Prather *J Urol* — in press)

FIG. 35

FIG 36

FIG. 35 · Bilateral single calculi in patient with partial cauda equina transection Stones were removed surgically. No recurrence of cal culi during the following six months.
(From Prather *J Urol* — in press.)

FIG 36 Multiple unilateral renal calculi in paraplegic patient which increased appreciably in size over a period of four months. (From Prather *J Urol* — in press)

There appears to be no specific method of correcting this situation either by dietary hormonal or drug therapy

If calculus disease becomes established in spite of our best efforts it is still often possible to overcome this diffi culty by surgery The paralyzed patient tolerates renal surgery surprisingly well In addition as time passes he becomes more ambulatory so that if a clean removal of calculi can be done the chance of recurrence becomes less

In the bedfast patient calculi which are asymptomatic and not associated with fever or hydronephrosis are not to be considered immediately surgical If possible, it is wiser to

mation will be appreciable We have been favorably surprised however, at the relatively low incidence of recurrence in our own series over a period of five to twelve months

Calculus disease in combination with infection is a serious threat to the welfare of the paraplegic patient The stone which is obstructing must be removed so that the present urinary antiseptic agents may be permitted their full effect

URETER

Calculi Ureteral stones descend from the renal pelvis and occur in the paraplegic patient as they do in any other group of patients The tendency of renal calculi to grow in size fairly rapidly and thus become too large to engage the ureter produces a higher ratio of renal stones to ureteral stones than seen in ordinary urological practice

The pain of ureteral colic is often absent in the paralyzed patient with a high anesthesic level Frequently it is a febrile reaction which calls attention to obstructive pathology in the urinary tract

The diagnosis is made by x ray and again intravenous urography provides information as to the degree of obstruction that the calculus is producing When there is uncertainty about the nature of an opaque shadow in the course of the ureter retrograde study especially in the oblique position may be required

Treatment of ureteral calculi becomes a matter of keen judgment in estimating the probability of spontaneous passage and manual dexterity not only with cystoscopic instruments, but with surgery

Calculi of passable size not causing a febrile reaction nor more than minimal dilatation proximally can be treated expectantly in the hope that they will descend to the bladder

come obstructive or scatter themselves in the ureter so that complete removal cannot be accomplished through one incision

Conservative renal surgery is paramount in the paraplegic patient because of the greater than average possibility of stone formation in the opposite kidney Kidneys which are grossly infected with multiple abscesses throughout the cortex will at times recover and maintain function when obstruction is relieved The presence of calculus disease of the opposite kidney often forces one to avoid nephrectomy even though the operated kidney appears gravely involved

FIG 38 Bladder stone in paraplegic patient with complete spinal cord transection in the upper dorsal region

These statements do not imply that nephrectomy should never be done With a normal kidney opposite a large pyonephrosis with a thin cortex, surgical judgment takes precedence over rules

Nephrostomy and irrigation with solution G of Suby and Albright has proved helpful but not universally successful in our hands Our experience confirms Bowie s finding that irrigation treatment by means of ureteral catheters is not successful

Unless ambulation is enforced and strenuous efforts are made to eradicate infection the recurrence of calculus for

sole irrigating medium In most instances the stones were small

With little or no sensation in the bladder symptoms of this disability are minimal The diagnosis is usually made by x ray or cystoscopy Chemical analysis usually showed that the stones were chiefly calcium phosphate and calcium carbonate

The treatment of multiple small calculi in the bladder has not proved difficult They can usually be crushed if necessary with the cystoscopic lithotrite and removed through the resectoscope sheath with the aid of the Ellik evacuator At times removal of calculi through a suprapubic sinus is feasible

Infection Long continued severe cystitis is likely to lead to reduced bladder capacity as found by Head and Riddoch They also found that any severe fever might tend to disturb previously established reflex action As reported by Ware (189) it is possible for a hypertonic small-capacity bladder to develop within two to three months after injury His case was an individual with a partial transection of the spinal cord and was improved following laminectomy

It is important to employ a program which will keep the bladder free of gross infection

Redundancy of Bladder Occasionally one sees a thick walled, flabby bladder which appears incapable of any muscular response It simply acts as a reservoir for urine and infection

Although the patients were not neurological problems Crabtree and Muellner 1948 (30) and Fish (50) have reported success by the surgical excision of about three fourths of the bladder wall Perhaps there will be a rare instance when this type of operation will be indicated after spinal cord injury

spontaneously. Frequent x ray examination will be required to watch their progress. Cystoscopic manipulation under these circumstances incurs a definite risk of infection above the calculus if the procedure is not successful

Calculi judged too large to have a good chance of passing spontaneously or those of borderline size which are responsible for a febrile reaction because of the infected kidney above it had best be removed by ureterotomy Surgery is tolerated well by the paraplegic patient and it provides a certain method of not only removing the stone, but relieving obstruction as well Ureteral incisions, like those in the kidney heal at a normal rate and fistula formation is uncommon. We have had an appreciable number of primary closures (of the ureter) with no urinary drainage from the wound after operation

BLADDER

Calculi. Bladder stones are not a direct menace to the life of the paraplegic patient but they interfere with rehabilitation of satisfactory bladder function and by irritation of ureteral orifices may be responsible for reflux or ascending infection

The *incidence of bladder calculi in military* personnel during the war who received spinal cord injury was apparently uniformly high Prather (145) reported an incidence of 30 per cent in patients with complete transection, and 14 per cent in those with partial transection. These figures are comparable to those of Raines and Bowie who found that 27 and 32 per cent respectively showed bladder calculi.

Stone formation occurred irrespective of suprapubic or urethral catheter drainage irrespective of tidal or manually controlled irrigation and during the use of solution M as the

process has begun Systemic use of sulfonamides and penicillin is logical and useful Surgical drainage is necessary only if a fluctuant abscess occurs In virulent infections the process may cause extensive scrotal sepsis necessitating epididymo-orchidectomy

Periurethral Abscess Infection in the glands of the urethra may become severe enough in one area to lead to abscess formation This occurs most frequently during periods of urethral catheter drainage and is not uncommonly due to too large a catheter A large catheter is also apt to produce pressure necrosis at angular portions of the urethra and cause abscess formation In the paralyzed patient catheters larger than No 18F enhance the probability of periurethral abscess

Abscess formation is most common at the penoscrotal angle and often causes sufficient inflammatory reaction to be momentarily confused with scrotal sepsis However careful palpation should lead to the correct diagnosis

The abscess itself is not serious but if urethral fistula results following evacuation of the pus the recovery of the patient to a voiding state is delayed sometimes by many weeks

Treatment of the abscess should be by systemic agents sulfonamides and penicillin and incision and drainage when required A small urethral catheter may permit intraurethral discharge of pus As in epididymitis cystotomy does not appear advisable once the process has become full blown since a change to suprapubic drainage at this point will not assuredly prevent the formation of a fistula

Urethral Diverticulum In general this lesion in the paraplegic patient is acquired and not congenital It is located usually in the anterior urethra, and caused from destruction of the urethral wall by inflammation or trauma

PROSTATE

With the employment of urethral catheter drainage over a long period of time, prostatitis of some degree is probably universal in the paraplegic patient but it rarely appears to be of clinical significance Since there appears to be no good reason to examine prostatic secretion in these patients data are not available

Prostatic abscess is apparently uncommon even in patients on urethral catheter drainage for many weeks Perhaps this might be explained at least in part by the dilated prostatic urethra which is common in many cases If the bladder neck and prostatic urethra are relaxed secretions from the prostate emerging into the urethra would flow back easily into the bladder

EXTERNAL GENITALIA

Epididymitis Infection in the epididymis may occur whenever there is urinary infection presumably by retrograde extension via the ejaculatory ducts and vas deferens Blood borne infection is also possible but in general tends to cause abscess of the testis rather than the epididymis Epididymitis is more common during periods of bladder drainage by urethral catheter than with a suprapubic tube

In the paralyzed patient symptoms are negligible but inspection of the swollen scrotum reveals the disease Associated fever is common

Treatment is the same as it is for the non-paralyzed patient Elevation of the scrotum is an accepted procedure which helps to relieve pain in the patient who has sensory appreciation Reverting to cystotomy drainage simply for this infection is hardly advisable once the inflammatory

the spinal cord All but three of the 27 cases were patients with complete transection

We know of no specific treatment although at times have been on the verge of requesting neurosurgical advice as to possible nerve section or block to overcome the condition

Impotency Reported studies have already been described in the section of this chapter entitled Changes in Sexual Organs After Spinal Cord Injury

RESULTS OF TREATMENT

An accurate survey of results of treatment as reported by many writers is difficult because the distinction between partial and complete transection has not always been maintained and often several methods of treatment have been employed in one patient One can therefore present only recorded statements with the understanding that all details may not be available

In 1917 Thomson Walker who did not differentiate between partial and complete transection found 55 days to be the average length of time for the first two stages of bladder recovery His cases were treated by intermittent catheterization and as mentioned previously the mortality rate was very high Apparently some of his cases later had cystotomy performed because 20 years afterward he reviewed the subject and reported on the results in a group whose injury had been more than 2 years past In a series of 100 cases 69 had resumed voiding with an automatic reflex bladder In those patients who had bladder capacity of 8 to 12 ounces he found a residual varying between 00 and 6 ounces Patients with larger capacity had a larger residual

It commonly follows periurethral abscess if the abscess does not lead directly to urethral fistula

Pate and Bunts (136) described 28 cases 26 of whom had a history of periurethral abscess All patients were on drainage with a urethral catheter at time the abscess first developed

In 402 paraplegic patients Pate and Bunts reported an incidence of 13 4 per cent of periurethral abscess. Histological examination of the excised diverticula showed a squamous metaplasia of the normal pseudostratified columnar epithelium They advised surgical excision and repair as the best treatment with diversion of the urine almost mandatory However only 3 of 10 operated cases healed well In addition they had trouble getting the perineal fistula healed when external urethrotomy was used to sidetrack the urine

Urethral Fistula Fistulae in the bulbous portion of the urethra tend to close more quickly than those of the penile urethra provided there is no obstruction distal to the opening They may close spontaneously in either area

If spontaneous closure does not occur fulguration of the sinus will aid the closure of a small fistula When the opening is larger surgical closure by plastic methods may be required as described by Cordonnier (29)

Priapism As a reflex mechanism, priapism is common in patients with spinal cord injury especially those with complete transection after the stage of spinal shock has passed It is usually recurrent each episode lasting from a few minutes to several hours The erection disturbs the adjustment of urethral catheters if adhesive tape fixation is used Hartwell (66) noted priapism in 27 of a series of 67 patients with injury of the cervical or thoracic portions of

the death rate of 64 per cent in injuries of the spinal cord

Riches reported a mortality rate of 62 5 per cent in complete transection of the spinal cord and 15 8 per cent in complete transection of the cauda equina In cases of partial transection of the cauda equina the reported mortality was 12.5 per cent as compared to 43 7 per cent for partial transection of the spinal cord

A later report by Munro (125) dealing with patients completely paralyzed below the waist indicated that 24 per cent of patients developed infection of the genito-urinary tract while being treated with tidal drainage but that infection was present in only 8 per cent of this group at discharge These figures are compared to an incidence of 20 per cent at discharge in a group in whom tidal drainage was used after other initial treatment and an incidence of 17 per cent when tidal drainage was not employed Sixty nine per cent of his group treated exclusively with tidal drainage showed no infection at any time

Reports by the same author on complications relative to the bladder and genital structures have indicated an incidence of 26 per cent in patients before tidal drainage was in use as compared to an incidence of 19 per cent during the past 6 years with an efficient tidal drainage system

Functional results have been tabulated by Munro in a series of 125 selected cases As listed in his table 4 complete urinary control was attained in 58 per cent when tidal drainage was used from the start, in 45 per cent when tidal drainage was used after an interval and in 79 per cent when tidal drainage was not used He does not say for what type of case the tidal apparatus was not used nor what type of treatment was used instead The reasons for failure in cases in which tidal drainage was used were variable They do not

Riches reported 30 patients studied in World War II in which no one form of treatment was used. In cases of injury of the spinal cord he found a period of 4 to 20 weeks before voiding was resumed (average of 12 weeks), while in those having injury of the cauda equina a period of 6 to 68 weeks passed before voiding took place (average 26 weeks). Periodic reflex micturition became developed best in supralumbar lesions, he found, and the residual urine was rarely over 2 ounces. Of 20 cases with incomplete transection, 9 recovered voluntary control after intervals of 1 day to 15 months. He found that the presence of a suprapubic tube for periods of 9 to 15 months did not prevent eventual return of micturition which was clinically normal except for the presence of infection and a 2 ounce bladder residual. During a period of 2 years there was a mortality rate of 28.5 per cent, one half of these caused by urinary tract infection.

Munro has reported the largest number of spinal cord injuries incurred in civilian life. In 1943 he reported an overall mortality of 57.5 per cent in 40 thoracic, and lumbosacral cord and conus injuries. Deaths due to genito-urinary sepsis were estimated as about 17 per cent of the total deaths. Some of these deaths, however, were due to operative accidents. In 100 cases of cervical cord injuries there was a mortality rate of 46 per cent, but genito-urinary sepsis was responsible in only 6.5 per cent of the total deaths.

Dennis (39) found that the higher the injury of the cord, the higher the mortality rate. In the Civil War he quotes the death rate for gunshot wounds of the cervical region as 70 per cent, of dorsal region as 65.5 per cent, and of the lumbar region as 43.5 per cent.

Cumston (34) found a mortality rate of 52 per cent in lesions of the cauda equina, evidently much less serious than

Martin and Davis (104) realized that automatic mic turition may develop in the presence of a complete lesion at any level of the cord or cauda equina although it develops most rapidly when the lesion is between C 7 and T 5

In their series of patients of 77 patients with cervical lesions 14 3 per cent developed automatic micturition of 288 patients with thoracic segment lesions 34 per cent de veloped automatic micturition of 106 lumbosacral lesions 16 4 per cent developed automatic micturition They found great variability in the quantity of residual in the automatic reflex type of bladder and also noted how changes in the pa tient s general condition would influence bladder activity

Medler (108) also reported on war injuries In a group of 122 cases (partial and complete transection) two-thirds were free of catheters at a time presumably averaging 8 to 15 months after injury

Prather studied a series of 61 cases of spinal cord in juries In 20 cases that had complete transection of the spinal cord there were 2 deaths in an average period of nearly 15 months from the time of injury 1 of whom succumbed with general sepsis that included the urinary tract The other death was caused by acute hepatitis Periodic reflex voiding had been established in 62 per cent without the use of tidal drainage or resection of the bladder neck Micturition oc curred at 1 to 4 hour intervals during the day with a longer interval during the night During the interval between uri nations there was no leakage of urine Bladder residual varied between 1 and 3 ounces Several weeks after re habilitation of the bladder had been accomplished the urine became grossly clear but showed positive cultures in the ma jority These patients were ambulatory in wheelchairs or on braces outdoors and indoors Some took trips to sur rounding towns via automobile

discredit this method and would contribute to the failure of any method Munro contends that in a selected group of one hundred cases only one patient in whom tidal drainage was properly used for a sufficient length of time failed to have infallible 24 hour control of urination at the time of discharge

Some years ago with only a brief experience with tidal drainage Munro (118) reported that the uninhibited normal cord bladder (reflex automatic bladder as used by us) had a storage capacity of less than 200 cc. in 90 per cent of cases and that the average residual was about 6 per cent of the fill End points of progress were reached between seventeen months and 17 years after injury There is no recent data by this author on bladder capacity amount of residual and rate of recovery in cases with complete transection of the spinal cord now that 10 years of experience with tidal drainage have been acquired A larger capacity may be inferred from his statement that patients can go a minimum of 3 hours during the day and the entire night without wetting themselves If one can assume a urinary output of 2 000 cc. per 24 hours *with 6 voidings at 3 hour intervals* during the day and none at night bladder capacity would be about 330 cc

Petroff has discussed the progress of patients injured in the recent World War Of 40 patients with complete tran section who had had suprapubic cystotomy overseas he had been able to transfer 42 5 per cent to tidal drainage and to develop reflex automatic urination in them within a period of approximately 1 year from time of injury Patients with partial transection could, in general be rehabilitated to a voluntary voiding status within 6 to 8 months from time of injury

They also used bladder neck resection to diminish or eliminate bladder residual in 16 cases with lesions above the 10th thoracic segment In their series there were 2 deaths

Their results indicated that 94 per cent were free of catheter drainage and that in the majority the urine was grossly clear Negative urinary cultures were reported in 39 per cent

The data from the above sources indicate that urological treatment of spinal cord injuries is now far more successful than it was twenty years ago Several factors are probably responsible Wider knowledge of the ability of the bladder to recover its functional activity has led to more energetic and successful attempts at rehabilitation to a state of satis factory voiding The greater cleanliness of a sterile closed system of drainage and irrigation has helped to reduce gross bladder infection and prevent an uncertain number of renal complications In addition, the more efficient urinary anti septics have saved lives and contributed to eventual recovery

Today the patient is justified in looking forward to bladder function that will permit a reasonable social exis tence

Influence of level of injury on end results The level as well as the extent of the spinal cord injury determines to some extent the final status of the bladder and the success of the long term program

Patients with complete cervical transection present special difficulties in rehabilitation of the bladder because they can not use their hands Since they are unable to use a urinary receptacle they are sometimes best left on suprapubic drain age However if a partial transection in the cervical region is unilateral the patient can handle a urinal satisfactorily and

Cases in whom voiding had not become re-established either were in poor general condition from associated injuries or had not sufficient reflex bladder activity as shown by cystometric study to re-establish voiding Those who had developed periodic reflex micturition did so within 3 to 10 months from time of injury — an average of 5 77 months After conversion from suprapubic drainage it was possible to develop an automatic reflex bladder with the suprapubic wound healed within a period of 4 to 8 weeks Most of his cases had had suprapubic cystotomy overseas A manually controlled system of irrigation was used during both suprapubic and urethral drainage in the majority of cases

Forty cases of partial transection of the cord or cauda equina caused by war injuries were studied by the same author up to 19 months from time of injury the personal study beginning after patients had been evacuated back to the United States In this series there were no deaths and 97½ per cent resumed voluntary voiding in normal quantities and with near perfect control Tidal drainage was used in only a few cases and resection of the bladder neck was necessary in only 1 case In patients who had had urinary retention for 1 month or longer the longest time from injury to resumption of voiding was 11 months and the average period was 3 months Fifteen per cent had resumed voiding less than 1 month after injury

Bumpus Nourse and Thompson have reported a series of 101 spinal cord injuries incurred in the Navy : Of 56 cases with injury below the level of the 11th thoracic vertebra they found it advisable to resect the bladder neck in 39 Following this procedure satisfactory urination was established in all but 3 They believed that the operation facilitated emptying of the bladder and contributed toward an eventual clear urine

age if voluntary straining and abdominal pressure do not produce satisfactory emptying

Partial lesions of the cauda equina may be associated with some incontinence with the patient in a standing position or during physical activity During attempted urination some straining may be necessary to empty the bladder

Spinal cord injury in the female Lack of wide experience in females with this type of disability prevents authentic statements for this group The progress toward recovery should be the same, however and the chance for urethral and genital complications less During the early phases of the illness it would seem imperative to use a balloon type catheter for drainage with either manual or automatic irrigation to prevent overflow incontinence, a wet bed and decubitus ulcers Rehabilitation to a satisfactory voiding state should be possible.

MILITARY POLICY

Although complete data are not available to us some information in regard to the urological problems of paraplegic patients can be summarized

MILITARY POLICY IN WORLD WAR I

There appears to be little official information in regard to spinal cord injuries in World War I The medical department of the United States Army lists 220 spinal cord injuries with a case fatality of eighty per cent There was no definite official program and it is indicated that only patients with partial cord injuries survived

Young (198) has stated that because at the time of World War I a course of non-intervention was generally

should look forward to a normally functioning bladder under excellent voluntary control

Patients with complete transection at the level of the upper and middle thoracic segments have an excellent chance of developing an efficient, socially compatible, reflex type of bladder as an end result The intervals between voiding may reach several hours and during the intervals no leakage of urine should occur In the supine position a bladder capacity of four to eight ounces is to be hoped for In the sitting position a larger amount may accumulate before a reflex contraction takes place A bladder residual of one to three ounces is not uncommon Those with partial transection at this level should attain an efficient bladder with voluntary control

In cases with complete transection at the level of the lower thoracic or lumbar segments the establishment of a reflex automatic bladder is less certain There are, however a number of reported instances in which very satisfactory reflex function has become established Bladder capacity is usually greater than with complete lesions at a higher level, and a longer interval between voiding can be anticipated if at the time of reflex contraction supplementary effort by straining or suprapubic pressure is used. These later aids may help to avoid a tendency toward a larger bladder residual than is commonly found in higher lesions

Patients with complete transection at the level of the cauda equina are unlikely to progress to an efficient type of automatic bladder although Denny Brown has reported cases which have Munro however is not optimistic and has found an inefficient autonomous bladder the typical end result In such an instance the bladder with an appreciable bladder residual may be best cared for by permanent drain-

necessary for correct use In addition associated wounds of the chest or abdomen often prohibited the immediately favored treatment

In spite of the known difficulties much thought was given to formulating a program, particularly in the European Theatre of Operations and long before D day The plans of Davis, Spurling and Scarf for neurosurgical centers in England to facilitate the care of spinal cord injuries have been related by Scarf (163) A program of tidal drainage for the care of the bladder was to be instituted and this method was proposed for cases injured in Europe Scarf says that the Chief Surgeon issued a directive just prior to the invasion date specifying that tidal drainage should be used It was thought that rapid air evacuation from the continent to England would facilitate this plan

Accordingly for some months paraplegic patients sent from France to England were all treated by tidal drainage on the continent Gradually, however patients began to be returned with suprapubic tubes As reported by Scarf, this was due to several factors primarily to the advent of new armies in the theatre for instance the 7th the 9th and the 15th Parts of the 7th Army had fought in the African desert and in the Italian mountains and their unique experiences in these difficult terrains undoubtedly justified their belief that suprapubic drainage was the only safe method Others simply had not come under the persuasion of the Chief Surgeon s Staff and had evolved their own doctrines

The lengthening lines of communication delay in prompt evacuation by adverse weather and changing personnel made continuance of the tidal drainage program impossible

Spurling (172) has also described the program in the European theatre Between D day and V E day 1206 para

believed best, the Manual of Military Urology suggested following this plan if possible Young did not know how successful this was but stated that it was apparently desirable to use catheterization or suprapubic drainage in many cases

Connors and Nash (28) reviewed policies of the various combatants and found that the British like the American forces never issued definite orders or instructions regarding treatment The French Army is believed to have used early catheterization and cystotomy later Inquiry by the above authors from German and Austrian sources was unproductive the reply stating that there were no statistics on the problem and no preferred method of treatment.

POLICY OF THE ARMY IN WORLD WAR II

At the beginning of the recent war there was no official policy regarding the urological treatment of spinal cord injuries This is readily explained Probably in no other type of injury were such divergent opinions positively expressed by various authors as to the proper or best treatment. Different methods of handling the bladder in civilian spinal cord injuries had been championed and denied with equal vigor by recognized urologists and neurosurgeons Experiences in World War I had failed to indicate any ideal form of treatment, but had demonstrated that the program of intermittent catheterization led to an appalling mortality It is therefore understandable that in this confusion no official policy could be honestly advocated Tidal drainage had been the only new form of treatment prescribed in ten years but care of war casualties might prohibit the use of this system until the patient could reach well equipped fixed installations Furthermore, there were relatively few acquainted with this apparatus its intricacies or the cystometric studies

common types of urological dysfunction that confronted the urologist in modern warfare and reported that management of the bladder still remains a debatable subject No conclusions could be drawn as to whether or not tidal drainage irrigation is essential because statistics on parallel groups of identical injuries were not available No conclusions could be drawn concerning the relative merits of various irrigating fluids used in tidal drainage but acid media appeared to be the most valuable Of 117 cases (extent of lesion not specified) treated with tidal drainage, 50 per cent had some degree of return of bladder function Of a group treated by catheter drainage in which tidal irrigation was not used 31 per cent had a comparable return of vesical function Of a group of 294 cases 199 required suprapubic cystotomy due either to early recognition of a hopeless lesion or failure to respond to urethral drainage Robinson found that patients who showed marked or complete improvement did so within 3 weeks He believed that suprapubic cystostomy after that time appeared to be the logical therapy to insure safety during evacuation or because of poor ultimate prognosis

Harrison (65) has summarized urological experiences in the Southwest Pacific theatre He has stated that best results were obtained when early continuous tidal drainage was used by either the urethral perineal or suprapubic catheter He found it possible to use the urethral catheter in many patients until an automatic bladder had been established although a few patients even with the best of care did not tolerate a urethral catheter For transportation over long distances by air or water the suprapubic catheter proved to be the easiest to care for and the safest method of drainage Suby s solution was used for irrigations

Harrison advocated biweekly cystometrograms to follow

plegic patients were treated in general hospitals in the United Kingdom Base alone The ideal care, he has stated consists of transporting the paraplegic patient from the battalion aid station to the nearest collecting station and sending him in an ambulance to the nearest evacuation hospital where his general condition could be evaluated and he could be prepared for prompt air evacuation to a neurosurgical center Insertion of an indwelling catheter was the only urological measure advised at this stage

Only about 50 per cent of the cases could be handled in this manner The remainder had to be cared for in evacuation and field hospitals for the first two or three weeks after injury

Once the patient arrived in a general hospital he was placed in a special ward with a urologist in charge The care of the bladder was considered the most urgent problem In some of the centers tidal drainage was used via the urethral catheter for several weeks At the end of that period if there was no return of spinal cord function a supra pubic cystotomy was performed Spurling states this was believed necessary to facilitate immediate treatment of uri nary sepsis and to make the patient ready for evacuation to the United States in the shortest possible time When the wound had healed well around the suprapubic tube and uri nary sepsis had subsided, the patient from a urological point of view was considered ready for evacuation Spurling found that it was not feasible to use tidal drainage continuously in an active theatre of war in a large group of casualties Fur thermore, it appeared impossible during the trip to the Zone of the Interior by any known form of transportation

Robinson (158) has also reported on experiences in the E.T O He found the neurogenic bladder one of the most

many cases This improvement was not accomplished over night but during a period of months excellent results were not only obvious but stimulating Attention was also given to obtaining a renal condition as near normal as possible.

A survey for the Surgeon General s office in October 1945 found that 948 of the 1430 paraplegic patients had suprapubic tubes on arrival in the Zone of the Interior Two hundred and thirty six or 16 per cent of 1430 patients were voiding on arrival in the United States

In May 1945 the office of the Surgeon General issued Technical Bulletin Medical 162 which made recommenda tions for the treatment of the paraplegic patient. This proved to be a stimulus for all who were charged with the care of this type of patient and yet left plenty of opportunity for individual professional accomplishment in these difficult cases Conferences and symposia were sponsored by the fifth ninth and second service commands during 1945 and led to a valuable interchange of ideas on this important problem

A survey of 1430 cases in Army general hospitals was made in October 1945 by Prather and Robinson (146) at the request of the Surgeon General s office As of that date 635 or 48 per cent had re-established bladder activity and were voiding Cases diagnosed as complete transection of the cord totaled about 642 Twenty nine per cent were void ing periodically with an involuntary reflex type of bladder activity 32 per cent were on urethral drainage and 39 per cent remained on suprapubic drainage Of 750 cases be lieved to have partial transection of the spinal cord 65 per cent were voiding with voluntary control It can be seen from these averages which of course do not represent the final accomplishment or end point in the rehabilitation of

progress being made toward automaticity Additional personnel were assigned for handling spinal cord injuries Cases under Harrison s charge did not develop renal or vesical calculi and automatic bladders were established before evacuation in one third of the patients

After arrival in the United States usually six to twelve weeks after injury (from the European theatre) paraplegic patients were sent to one of a number of neurosurgical centers located in Army general hospitals The trip from overseas had often been an arduous one whether by air or by ship

Thorough re evaluation of the urinary tract by x ray intravenous urography cystometrograms and cystoscopy was instituted and treatment continued The urological program was at first left to the ability ingenuity and resourcefulness of the urologist at each of these centers designated for the care of the paraplegic patient. Also enlisted for the welfare of these patients were capable representatives in various special fields such as neurosurgery orthopedics plastic surgery nursing dietetics physiotherapy occupational therapy and recreation Red Cross and the ministry Rehabilitation of the patient with this difficult type of injury became a challenge to many fields of medicine

Organized and improved urological treatment became necessary to handle the large number of patients Sterile closed systems of drainage and irrigation were instituted by some

Cystometric studies disclosed that many bladders were capable of resuming function so that it was possible to institute urethral catheter drainage with a closed system of drainage while the suprapubic wound healed The final steps removal of the catheter a training period for the bladder and either reflex or voluntary voiding proved successful in

of war we do not yet know, nor do we know the mortality rate in cases who survived the initial shock of injury and were returned to the United States However scattered reports from neurosurgical centers in the United States indicate a remarkably low mortality rate during the first year in this latter group — probably not over 6 per cent, and these not all due to urological causes What will happen during coming years is difficult to say Patients who have not been discharged home have been transferred to Veterans Administration hospitals for further care and statistical data must necessarily come from that source

From the experiences in World War II certain facts concerning urological care of spinal cord injuries in war become apparent

The soldier with bladder paralysis should have constant bladder drainage by means of an 18F urethral catheter connected to a sterile closed drainage system during the early part of his illness Frequent irrigation of the bladder is important and can be accomplished by a tidal apparatus or by manual control

If neurosurgical survey indicates a partial transection of the spinal cord, urethral catheter drainage can be maintained with hope of recovery of bladder function in a period of weeks

If neurosurgical opinion indicates a severe injury with probable complete transection of the spinal cord and transportation over long distances is necessary a high suprapubic cystotomy with manual irrigation by means of a sterile closed system offers a safe program

X ray study of the upper urinary tract by means of intravenous urography at intervals of several weeks is advisable to properly interpret febrile episodes if they occur

the bladder, that commendable progress had been made during a period of months after the injury

The survey produced further interesting statistical data. Fifty six cases of periurethral abscess were reported forty eight of which occurred during urethral catheter drainage. One hundred and seventy nine instances of epididymitis were related 126 of which occurred during urethral catheter drainage

The most common bacteria found in the urine proved to be B Proteus B Aerobacter Aerogenes B Pyocyaneus, B Coli, Streptococcus Fecalis Hemolytic Staphylococcus and Non hemolytic Streptococcus

Drugs had not proved helpful in promoting bladder activity Resection of the presacral nerve was reported in two cases but both of these were failures Resection of the bladder neck to facilitate emptying of the bladder had been tried in thirty three cases at that time with good results in nineteen and poor results in fourteen

Inquiry among the urologists on duty at neurosurgical centers yielded the following opinions Twenty believed it advisable to aim for resumption of voiding in the paraplegic patient, while two did not believe the effort worthwhile Nine believed tidal drainage was necessary for the eventual rehabilitation of the bladder but sixteen disagreed with that opinion Twenty three advocated cystometric study periodically to determine the status of the bladder although three did not believe this type of examination helpful

Urinary tract calculi proved to be an important potential or actual complication It is known from the above survey that at least 12 3 per cent had renal calculi and that at least 20 per cent had bladder calculi

The mortality rate in spinal cord injuries in active theatres

There appears to be no reason to catheterize the bladder until urinary retention has been demonstrated However when it becomes evident that the bladder will not immediately resume function, the patient should be catheterized under strict aseptic precautions with a number 18F two-holed soft rubber catheter The catheter should be arranged for constant drainage and connected to a sterile closed drainage system with provision for closed irrigation either manually or automatically controlled

If neurosurgical survey indicates that a partial transection of the spinal cord has occurred, plans can be made to continue the urethral catheter program with the hope that voluntary bladder action will be re-established in a period of weeks If neurological survey indicates that there is complete transection of the spinal cord the urethral catheter program can be continued unless contraindications appear, or suprapubic cystotomy can be done and the tube connected to a closed drainage system In cases of complete transection a number of weeks may elapse before a reflex type of automatic bladder is established. With either the urethral or suprapubic drainage program frequent irrigations under aseptic conditions must be used and catheters or tubes changed periodically before they become obstructed or encrusted

Fluid intake and output must be maintained at a high level and the general state of nutrition watched carefully

Routine tests of renal function as determined by blood chemistry and phenolsulphonphthalein excretion should be made and repeated at intervals to be determined

Cystometric determinations should also be recorded at intervals of one to two weeks to note progress of recovery of bladder musculature

Cystometric study periodically is necessary to determine the proper time to aim for rehabilitation of the bladder

Tidal drainage is a good method of bladder irrigation but is not necessary for rehabilitation of the bladder to a satisfactory voiding state

Cleanliness gentleness and personal ability remain important factors in urological technique and treatment

Resection of the bladder neck may aid certain cases to re-establish voiding

Penicillin streptomycin and sulfonamides have been helpful in controlling urinary infection

Renal surgery is necessary at times to save life and to prevent deterioration of renal substance.

The aim should be re-establishment of the bladder as a satisfactory functioning organ and this can be accomplished in the majority of cases

SUGGESTED PROGRAM FOR TREATMENT

Before concluding this monograph we shall outline a possible program for the care of the urinary tract in cases of spinal cord injury The following statements are not intended as the last word on this subject The suggested program represents simply our opinion based on an academic review of contributions of many authors and our personal experience in the rehabilitation of patients during the recent war We believe that this program is as foolproof as any and that it should lead to a urinary tract as functionally efficient as the extent of the injury allows We acknowledge that a successful result depends as much on the skill and attention of those in immediate charge as on the several possible methods of treatment

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Urinary studies including culture should be made frequently

X ray study of the urinary tract by intravenous pyelography should be done as soon as practicable and repeated at intervals of several weeks

Sulfonamides and antibiotic agents need not be used routinely for the urinary tract, but will prove helpful if upper urinary tract infection occurs

As soon as ambulation has been achieved or is in immediate prospect and the bladder shows a satisfactory cystometric response measures must be undertaken to accomplish satisfactory voiding

If voiding is not resumed as might be expected by combined urological and neurological examination, cystoscopic study of the bladder and bladder neck are justified When neurological improvement has reached a maximum, if there is evidence of bladder neck obstruction resection of this region should be considered Neurological procedures such as temporary or permanent nerve blocks may be required to provide acceptable bladder capacity and the proper balance between detrusor contractions and urethral resistance

Urinary antiseptics should be used vigorously after bladder drainage has been terminated if urinary infection is present

A sincere interest in the welfare of the patient a strict attention to aseptic conditions and an understanding of the aims of treatment on the part of the medical and nursing staff are essential for progress

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Chapter IV

PROBLEM OF NUTRITION

A M KLEINMAN MD

INTRODUCTION

Loss of body weight is the outstanding clinical manifestation of malnutrition in patients with spinal cord injury It is also a prominent finding in acute and chronic infection malignancy severe trauma operation hepatitis uncontrolled diabetes hyperthyroidism and many other diseases One of the remarkable features of this weight loss is the rapidity with which it occurs A significant decrease in weight may be observed within a very few days after an injury an operation or the onset of an infection, even of such an apparently innocuous one as an upper respiratory infection Loss of weight often occurs early in the course of diseases with insidious onset such as tuberculosis or malignancy before other signs of systemic disturbance are evident The ease and rapidity with which weight is lost under these diverse and unrelated conditions are in sharp contrast to the difficulties usually encountered by the otherwise normal obese in reducing It is evident that there must be a common metabolic response to a great variety of bodily insults to explain these phenomena The nature of the response will be discussed later

Regardless of the cause it has been known for many years that this abnormal weight loss could be minimized

by dietary means The importance of a full diet in tuberculosis is generally recognized The classical work of Shaffer and Coleman (1) in 1909 demonstrated the therapeutic value of a high caloric intake in typhoid fever The increased metabolic demands in hyperthyroidism are universally appreciated and careful attention is usually paid towards meeting them But in many other conditions and especially in trauma and surgical procedures the important matter of preventing minimizing or even treating malnutrition is still grossly neglected in spite of the teachings of Cuthbertson Howard Elam Co Tui and others Among patients suffering from spinal cord injuries, malnutrition was as common in casualties of World War II as in World War I Fully 80 per cent of these cases during World War I died within the first few weeks (2) and presented a clinical picture of cachexia associated with uncontrolled infection and extensive decubitus ulceration During World War II the mortality was much lower due to advances in the treatment of shock and infection and to the development of newer surgical techniques But loss of weight was universal and emaciation common The deleterious effects of malnutrition on wound healing on the development and persistence of decubitus ulcers on resistance to infection, and on mental and emotional reactions make it necessary to study the manifestations and causes as well as the means of minimizing and curing such malnutrition in these cases

CLINICAL MANIFESTATIONS

The following observations were made on a group of 82 patients with spinal cord injuries who were studied at an Army General Hospital in the United States The majority of the patients were battle casualties but a consider

able number had sustained their injuries in ways comparable to civilian accidents e g, collisions between motor vehicles overturning of jeeps crash landing of airplanes etc A large number particularly the battle casualties had associated with their spinal cord damage a variety of other types of injuries, each with its characteristic complications and sequelae These associated injuries included chest, abdominal and soft part wounds and fractures of one or more bones

The outstanding clinical feature from the nutritional standpoint, was the rapid and marked loss of weight This occurred promptly after the injury and reached a maximum within a few weeks The average weight loss was 49 41 pounds Only three patients lost less than 20 pounds Twenty nine patients lost between 21 and 40 pounds 30 patients between 41 and 60 pounds 16 between 61 and 80 pounds and three between 81 and 100 pounds One patient lost 102 pounds In 41 cases no weight was regained between the date of injury and the date of admission to the General Hospital, a period which averaged 80 days In the other 41 cases the weight regained averaged 17 pounds but the interval from the date of injury to the date of admission was 151 days, nearly twice as long

A wasted appearance was striking in all patients whose weight loss was substantial There was obvious loss of muscle mass and muscle tone was greatly diminished in the non paralyzed muscles The skin was pale dry and lacked turgor and elasticity Decubitus ulcers were present in about 78 per cent of the cases Infected draining sinuses and fistulae were common Infection of the urinary tract was universal and a high percentage of patients developed urinary calculi Clinical evidence of vitamin deficiency was

rare. No cases of nutritional neuropathy or of scorbutic petechiae, hemorrhages or gum lesions were seen Frank glossitis was noted in two patients one of whom had chei losis Suggestive lesions were noted in a few others Frank nutritional edema was present in only one case It is possible that laboratory studies might have furnished evidence of subclinical vitamin deficiencies but such studies were not made

Anorexia was present in all cases, and there was a par

TABLE I

BLOOD PROTEINS

Case No	Number of Observation	Average Total Protein Gms per 100 cc.	Lowest Total Protei Gms. per 100 cc.	Number of Results Below 6 0 Gms. per 100 cc.
1	5	7 3	7 0	0
2	2	6 8	6 8	0
3	9	7 0	6 0	0
4	15	6 4	5 9	2
5	1	7 2	—	—
6	8	6 3	5 5	2
7	1	7 6	—	—
8	1	6 1	—	—
9	13	6 6	5 4	1
10	4	6 4	6 2	0
11	6	6 7	6 3	0
12	8	7 2	6 5	0
13	2	6 2	6 2	0
14	7	6 7	5 7	1
15	6	6 5	5 8	1
16	4	6 4	5 7	1
17	8	6 8	5 9	1
18	10	7 0	6 0	[illegible]
19	2	7 1	6 6	0
20	3	7 0	6 3	0

MILK FORMULA 1 * †

FOOD	Gms	C	P	F	Cal	Ca	P	Na	Cl
Powdered Skimmed Milk ⅔ cup	100	52	35	1	355	1 180	880	400	800
Skimmed Milk 1 pint	500	25	17 5	1	180	610	480	255	550
Egg Whites—6	150	—	18	—	70	023	021	255	233
TOTAL		77	70 5	2	605	1 813	1 381	910	1 583

* Figures represent amounts per quart.

† Vanilla, chocolate or other flavoring added to formula, with sugar to each individual's taste

MILK FORMULA 2 * †

FOOD	Gms	C	P	F	Cal	Ca	P	Na	Cl
Powdered Skimmed Milk 1¼ cups	175	91	61	2	625	2 065	1 540	740	1 400
Skimmed Milk 1 pint	500	25	17 5	1	180	610	480	255	550
Egg Whites—6	150	—	18	—	70	023	021	255	233
TOTAL		116	96 5	3	875	2 698	2 041	1 250	2 183

* Figures represent amounts per quart.

† Vanilla, chocolate or other flavoring added to formula, with sugar to each individual's taste

rare. No cases of nutritional neuropathy or of scorbutic petechiae hemorrhages or gum lesions were seen Frank glossitis was noted in two patients one of whom had cheilosis Suggestive lesions were noted in a few others Frank nutritional edema was present in only one case It is possible that laboratory studies might have furnished evidence of subclinical vitamin deficiencies but such studies were not made

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3	9	7 0	6 0	0
4	15	6 4	5 9	2
5	1	7 2	—	—
6	8	6 3	5 5	2
7	1	7 6	—	—
8	1	6 1	—	—
9	13	6 6	5 4	1
10	4	6 4	6 2	0
11	6	6 7	6 3	0
12	8	7 2	6 5	0
13	2	6 2	6 2	0
14	7	6 7	5 7	1
15	6	6 5	5 8	1
16	4	6 4	5 7	1
17	8	6 8	5 9	1
18	10	7 0	6 0	0
19	2	7 1	6 6	0
20	3	7 0	6 3	0

Milk Formula 5 * †

FOOD	Gms	C	P	F	Cal	Ca	P	Na	Cl
Dryco ⅔ cup	100	46	32	12	420	1 000	810	400	800
Milk 1 pint	500	25	17 5	20	350	600	465	255	530
Eggs	3	—	18	18	235	102	336	210	159
Van Ice Cream ½ pint	125	28	5 5	15	270	188	150	—	—
TOTAL		99	73 0	65	1275	1 890	1 761	865	1 489

* Figures represent amounts per quart.

† Vanilla, chocolate or other flavoring added to formula, with sugar to each individual's taste

Milk Formula 6 * †

FOOD	Gms	C	P	F	Cal	Ca	P	Na	Cl
Dryco 1 cup	150	69	48 0	18	630	1 500	1 215	600	1 200
Milk 1 pint	500	25	17 5	20	350	600	465	255	530
Eggs—4	200	—	24 0	24	310	136	448	280	212
Van Ice Cream ½ pint	125	28	5 5	15	270	188	150	—	—
TOTAL		137	95 0	77	1560	2 424	2 278	1 135	1 942

* Figures represent amounts per quart.

† Vanilla, chocolate or other flavoring added to formula, with sugar to each individual's taste.

MILK FORMULA 3 * †

FOOD	Gms or cc	C	P	F	Cal	Ca	P	Na	Cl
Dryco 3/5 cup	100	45	32	12	420	1 000	810	400	800
Skimmed Milk 1 pint	500	25	17 5	1	180	610	480	255	550
Egg Whites—5 plus 1 Yolk	175	—	20 5	6	135	043	110	269	247
TOTAL		70	70 0	19	735	1 653	1 400	924	1 597

* Figures represent amounts per quart.

† Vanilla, chocolate or other flavoring added to formula, with sugar to each individual's taste

MILK FORMULA 4 * †

FOOD	Gms or cc	C	P	F	Cal	Ca	P	Na	Cl
Dryco 1 1/3 cups	185	85	59	22	775	1 850	1 498	740	1 480
Skimmed Milk 1 pint	500	25	17 5	1	180	610	480	255	550
Egg Whites—6	150	—	18	—	70	023	021	255	233
TOTAL		110	94 5	23	1025	2 483	1 999	1 250	2 263

* Figures represent amounts per quart.

† Vanilla, chocolate or other flavoring added to formula with sugar to each individual's taste

the sodium thiocyanate method with a tendency to an increased volume for the group as a whole These findings may be interpreted as indicative of a significant decrease in blood volume due chiefly to anemia The slight decrease in the quantity of the total circulating plasma proteins was accompanied by a decrease in plasma volume explaining the normal plasma protein concentration

Similar manifestations of malnutrition have been observed by others not only in patients with spinal cord injuries but after any type of severe trauma Rappaport (4) in postmortem examinations of six cases of traumatic spinal cord lesions found three common features (a) extreme emaciation (b) severe anemia, and (c) a spreading inflammation regardless of anatomic barriers indicating a loss of general and local resistance Champ Lyons (5) reported weight losses of from five to 30 kilograms in patients with chronically infected gun shot fractures His patients too showed reductions of blood volume, deficits of total circulating hemoglobin and increased amounts of extracellular fluid The plasma proteins were normal

To summarize the clinical manifestations of nutritional deficiency patients with traumatic lesions of the cord show (a) marked loss of weight which is persistent and which is regained with extreme slowness and difficulty (b) slight plasma protein deficiency which is masked by a concomitant decrease in plasma volume (c) moderate to severe anemia (d) a tendency to an increase in the amount of extracellular fluid which is indicative of a tendency to edema formation although visible edema is not common (e) marked anorexia The paucity of clinical signs of vitamin deficiency is noteworthy The relationship between nutritional deficiency and resistance to infection, decubitus

ticular aversion to meats during the period of marked inanition. A check of the dietary intake of many patients who claimed to be eating well revealed daily caloric values below 1,000 and protein values of 50 grams or less. Most of the patients were emotionally unstable. One or more of the following disturbances, in varying degrees, were observed in nearly all patients: excessive irritability, resentment, temper tantrums, depression, disinterest, apathy and impairment of ability to concentrate. These emotional symptoms appeared to vary in intensity with the degree of inanition.

Anemia, varying in degree, was found in nearly every patient. The results of blood protein examinations in 20 cases are listed in Table 1. The number of observations in different cases varied from one to 15. Seven patients had levels below 6.0 grams per 100 cc. at some time during the period of observation, but most of the results were within the normal range.

Ling and Sprinz (3) studied the blood and plasma changes in similarly wasted patients. Their group consisted of 27 individuals, including five of the 82 spinal cord cases, who showed marked weight loss following traumatic injuries. The average weight loss in their group was 50 pounds, practically identical with the average in the spinal cord group. There was a 7 per cent decrease in the quantity of total circulating plasma proteins, although the concentration remained normal. The blood volume showed a decrease of 26 per cent, the plasma volume of 11 per cent, the red cell volume of 40 per cent, and the total circulating hemoglobin of 37 per cent below the values obtained in a group of 50 normal adults. There was a considerable variation in the amount of extracellular fluid as measured by

the sodium thiocyanate method with a tendency to an increased volume for the group as a whole These findings may be interpreted as indicative of a significant decrease in blood volume due chiefly to anemia The slight decrease in the quantity of the total circulating plasma proteins was accompanied by a decrease in plasma volume, explaining the normal plasma protein concentration

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ulcers urinary calculi and emotional instability all of which are commonly observed in paraplegics will be discussed later

It is of interest to compare the findings in cases of trauma with those observed in patients who have undergone prolonged semi starvation in Japanese or German prisoner of war camps McDaniel White and Thompson (6) have reported their findings in a group of 1 520 repatriates who were liberated from four Japanese detention camps In addition to emaciation, clinical evidence of vitamin deficiency was common. Visible edema, or a history of visible edema, was noted in 68 per cent of one group who had been interned for an average period of 17 months, and in 44 per cent of another group who had been interned for seven months Psychically these patients showed apathy indifference and spotty amnesia Mean values for plasma protein concentrations were normal, but three of the patients with edema had low values Similar findings were noted in large numbers of Japanese and German repatriates observed in the aforementioned Army General Hospital The differences between the traumatized and the repatriated patients consist of a higher incidence of visible edema and vitamin deficiency and a more rapid return of appetite and weight in the latter These are essentially the differences between malnutrition resulting from the metabolic response to injury and malnutrition due to prolonged dietary imbalance and inadequacy

CAUSES OF MALNUTRITION

The loss of weight which invariably follows severe trauma or infection is accompanied by an obvious reduction in muscle mass, indicative of a loss of protein tissue. Nutritional deficiency under these circumstances really repre

sents a deficiency of protein A discuss on of the etiology of malnutrition in patients with traumatic lesions of the spine is therefore concerned primarily with the causes of protein deficiency and the mechanisms by which it is pro duced

NITROGEN BALANCE

Proteins are taken into the body by ingestion in the form of food or by injection in the form of blood, plasma, albu min, protein hydrolysate or amino acid mixture The latter *two may also enter by ingestion Proteins leave the body* usually in the form of non protein nitrogenous excretory products or occasionally in the form of blood plasma or exudate Information about the quantitative relationship between the total intake and output of these substances is im portant because it indicates whether the body is gaining or losing protein Since not all of these substances are proteins but they all contain nitrogen determination of the difference between total nitrogen intake and output provides the necessary information Those nitrogenous substances present in food which are not proteins or protein derivatives are neg ligible in amount and may be disregarded

The end products of protein metabolism are excreted in the form of non protein nitrogenous compounds The chief vehicle for excretion is the urine some nitrogen being lost in the stools and a very small quantity in the sweat The amount of nitrogen excreted in the feces is usually constant on ordinary diets and averages between one to two grams a day (7) Diarrhea or an excess of indigestible material in the food may increase the amount of nitrogen in the stools The excretion of nitrogen in the sweat is negligible except in the presence of profuse diaphoresis (7) Under ordinary circumstances, therefore, variations in the amount

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almost complete starvation As the food intake declines the reserve stores of carbohydrate and fat are utilized and when these are nearly gone tissue proteins are drawn upon to supply energy

Much more important than inadequate intake in the production of a negative nitrogen balance is the excessive nitrogen loss which occurs in traumatized patients Part of this loss may be attributed to actual hemorrhage plasma lost from the surfaces of burns and wounds and to protein lost in exudates from infected wounds, decubitus ulcers etc But by far the most important factor is the excessive loss of urinary nitrogen the result of a metabolic response to injury

METABOLIC RESPONSE TO INFECTION AND INJURY

The metabolic responses which are set in motion when an individual is subjected to trauma, infection or other bodily insult are only now beginning to receive the attention their importance warrants The alteration in protein metabolism the so-called toxic destruction of protein which is associated with infectious disease has been recognized since before the turn of the century That similar alterations occur in response to trauma has been known since 1930 when Cuthbertson (8 9 10 11 12 13) published the first of a series of papers dealing with this subject but their full significance and far reaching implications did not become apparent until the recent war

NITROGEN METABOLISM IN INFECTION

It was known for a great many years that during the course of certain infectious diseases notably typhoid fever there was an excessive urinary nitrogen excretion resulting

of nitrogen excreted are reflected chiefly in the urine In certain pathological conditions nitrogen may be lost through the oozing of plasma from the surfaces of burns and wounds in exudates from suppurating lesions by effusions into serous cavities and from frank hemorrhage.

In the normal adult the total nitrogen intake is equal to the total nitrogen output and the subject is said to be in nitrogen equilibrium When the intake is greater than the output a positive nitrogen balance is said to exist and is indicative of protein gain This occurs during active growth and also when depleted tissues are replenishing their protein stores When the output of nitrogen exceeds the intake a negative balance exists and is indicative of protein loss This occurs in starvation, in conditions characterized by excessive protein catabolism or by insufficient protein anabolism and through actual loss of protein such as in burns, hemorrhages exudates etc Since each gram of nitrogen represents 6 5 grams of protein, the net loss or gain of protein may be calculated from the nitrogen balance

CAUSES OF PROTEIN DEFICIENCY

A long continued negative nitrogen balance eventually results in depletion of the tissue proteins thereby producing a state of protein deficiency This occurs in patients with spinal injuries in whom the negative balance is due both to inadequate nitrogen intake and excessive nitrogen loss The low caloric and low protein intake of many patients who are supposedly eating well has already been mentioned Anorexia and abdominal wounds involving the gastro-intestinal tract obviously contribute to the low food intake As the degree of inanition becomes worse mental and emotional symptoms appear and aggravate the increasing anorexia setting up a vicious cycle which may lead ultimately to

previous nutritional state of the individual The adminis tration of generous diets or of protein hydrolysate intra venously failed to prevent nitrogen loss

Noteworthy in the series of papers from the Russell Sage Institute was the different behavior of patients with tuber culosis McCann and Barr (16 17) showed that in these patients the nitrogen loss was not excessive and could readily be prevented by a diet containing from 60 to 90 grams of protein and total calories of about 2 500 These patients had previously lost considerable weight and were in a chronically undernourished state as compared with patients suffering from acute febrile illnesses who had been in previous good health

NITROGEN METABOLISM IN INJURY

The present knowledge with regard to the metabolic re sponse to injury is due chiefly to the work of Cuthbertson, confirmed and amplified by Howard (19 20 21) Browne (22), Grossman (18) Peters (23 24) and others Im mediately after injury the urinary nitrogen excretion is normal Within a day or two however it begins to increase rapidly to reach a peak between the fourth and the eighth days after the injury This period has been called the early catabolic period The height of the peak, or the degree of nitrogen loss varies with the nature and severity of the in jury After operations the peak is lower and is reached earlier between the second and fourth days The excessive nitrogen loss continues after the peak has been reached, but at a lower level This period has been called the late cata bolic period and after severe injuries such as fractures the entire catabolic period may last for six to eight weeks or longer The catabolic period is followed by one in which a

in a negative nitrogen balance This nitrogen loss was attributed to a toxic destruction of protein and was believed to be due to the toxemia of the disease Shaffer and Coleman in their classical study of protein metabolism in typhoid fever published in 1909 (1) proved that the nitrogen loss was greater than could be attributed to the combined effects of the elevated temperature itself and the dietary regimen of semi starvation then in vogue They showed that a diet of from 3 500 to 5 200 calories and containing an adequate amount of protein could minimize or reverse the negative nitrogen balance In a subsequent paper Coleman and du Bois (14) demonstrated that typhoid fever patients showed a negative nitrogen balance in spite of a diet which furnished more calories than the actual body heat expenditure as measured in a calorimeter Loss of weight usually ran parallel with loss of protein In some cases protein loss continued for days after the fever had subsided Similar results were reported in patients with malaria (15) arthritis erysipelas and a number of other infections The conclusion arrived at by this group of investigators at the Russell Sage Institute was that the negative nitrogen balance in infectious fevers could be minimized but not prevented by a diet adequate in protein content and providing considerably more calories than the calculated requirement More recently Grossman et al (18) studied 45 patients with various medical and surgical conditions the medical ones including meningococcus meningitis pneumococcus pneumonia, scarlet fever upper respiratory infections subacute bacterial endocarditis lung abscess peritonsillar abscess rheumatic fever regional enteritis and skin infections The patients wasted nitrogen to a variable degree and for variable periods of time depending on the severity of the infection and on the

same day by the excretion of practically the entire nitrogen content (22) The nitrogen of intravenously administered amigen behaves as does food nitrogen but the nitrogen of intravenously administered plasma is retained (22) Diets with a value as high as 5 000 calories per day have failed to prevent negative nitrogen balance during the early catabolic period (13) If attempts are made to establish nitrogen equilibrium at this time it is found that with a rise in protein intake more nitrogen appears in the urine maintaining the negative balance unchanged (20) During the late catabolic period it may be possible to establish nitrogen equilibrium with a sufficiently high caloric and protein intake

At the present time it is doubtful whether any dietary measure can overcome the negative nitrogen balance during the early phase of the reaction Croft and Peters (27) have reported a substantial reduction in the nitrogen lost by rats after thermal burns when a high protein diet was fortified by the addition of methionine Stevenson (30) has reported that 30 mgm of methionine is as effective as 400 mgm of nitrogen from egg protein in reducing the nitrogen excretion of animals on a low protein diet The sparing action of methionine on nitrogen loss is maintained when the caloric intake is cut to as low as 25 per cent whereas the sparing effect of egg protein is lost at 50 per cent If confirmed the addition of methionine to the diet may therefore eventually prove to be a method by which the excessive catabolism after injury can be reduced The nitrogen lost during the catabolic period is replenished very slowly Three of Howard s fracture cases followed for 24 59 and 45 days regained only 18 per cent 14 per cent and 1 6 per cent of the original losses respectively It will be recalled that half of our spinal cord cases regained none of their lost weight in

positive nitrogen balance is readily attained. However even mild intercurrent infections and slight disturbances such as physical exertion or the changing of a cast may lead to increased nitrogen excretion and negative nitrogen balance, if these disturbances occur during the earlier part of the anabolic period The catabolic loss of nitrogen after operative procedures is smaller and the period shorter In Howard s fracture cases (19) the duration of the catabolic period was 35 days and the total nitrogen lost during this period averaged 220 grams per patient. Since each gram of nitrogen represents 6 25 grams of protein the average quantity of protein lost amounted to 220 × 6 25 = 1375 grams Protein constitutes about 20 per cent or one fifth of muscle tissue Assuming that most of the protein lost was derived from muscle, the loss of 1375 grams of protein represents the loss of 1375 × 5 = 6875 grams or about 15 pounds of muscle In Howard s osteotomy cases the average duration of the catabolic period was nine days and the average nitrogen loss was 40 grams equivalent to about three pounds of muscle tissue Much greater losses have been observed by others following operative procedures Elman (25) reported a decline of 25 pounds in one patient after a relatively uncomplicated cholecystectomy

The catabolic response has been described in a great variety of bony and soft part injuries (8 9 10 11 12 13 18 19 20 21 22 23 24) after burns (26 27) after hemorrhage (28) as the result of operative procedures (10 12 18 19 22 23) in the course of infectious disease (1 14 15 18 22 23 24) and during experimentally produced acute sterile inflammation (29) During the peak of the catabolic period oral intake of a diet containing as much as 2,000 calories and 100 grams of protein is followed on the

increase in nitrogen output after fracture of the femur Madden and Clay (29) demonstrated little or no increase in nitrogen excretion in protein depleted dogs in contrast to a large increase in excretion in well nourished dogs following the production of acute sterile inflammation by the injection of turpentine

FACTORS TO BE EVALUATED IN CATABOLIC RESPONSE

In attempting to account for the metabolic response certain factors must be evaluated These factors are (1) effect of fever (2) starvation (3) disuse atrophy and bed rest and, (4) reflex trophic effect.

(1) Effect of Fever That nitrogen loss in infectious disease exceeds that to be expected from fever alone has already been indicated in connection with the reports from the Russell Sage Institute In Shaffer and Coleman s (1) study of typhoid fever a negative nitrogen balance persisted well into the convalescent period in one case in spite of a high caloric and high protein intake. In another case, a negative balance resulted during convalescence when the total caloric intake was reduced somewhat, although the protein intake remained high In Coleman and du Bois s cases (14) protein catabolism continued into the convalescent period in some of the subjects Patients with malarial fever excrete far more nitrogen than can be accounted for by a 7 per cent increase in total metabolism for each degree of fever In the studies of Grossman and his associates (18) negative nitrogen balance persisted in meningococcus meningitis and in scarlet fever after the temperature had become normal and signs and symptoms of the disease had disappeared With regard to trauma most of the patients

80 days, while the other half regained an average of only 17 pounds (34 per cent of the original loss) in 151 days. Repletion following operation occurs more readily

VARIATIONS IN INTENSITY OF CATABOLIC RESPONSE

The intensity of the catabolic response varies with the nature and severity of the injury or infection It is much more intensive after bony fracture than after osteotomy It is more severe in typhoid fever and meningitis than in some other infections Operative procedures in general cause a milder response than traumatic injuries Multiple injuries combined with secondary infection, as occurs so commonly in patients with fractures of the spine will obviously produce an extremely severe metabolic reaction A factor which causes important variations in the degree of response is the nutritional state of the individual at the time of the injury McCann and Barr (16 17) showed that in tuberculosis the urinary nitrogen loss was not excessive, and that positive nitrogen balance could readily be attained These patients had lost considerable weight at the time of the study It has since been demonstrated (22) that the chronically ill from whatever cause show a catabolic response to injury or infection, but that they differ from healthy adults in that raising the protein intake to moderate levels does not lead to the immediate excretion of all the food nitrogen These patients can thus be brought into nitrogen equilibrium earlier and at a lower level of intake The difference in response between the well nourished and the poorly nourished has been confirmed experimentally Munro and Cuthbertson (31) showed that in rats who had been fed on a protein free diet until the nitrogen excertion had fallen to a steady level there was no

in casts after osteotomy were subjected to the same degree of immobilization as the fracture cases Yet, in the latter group the nitrogen loss was of greater degree and of longer duration Simple disuse and bed rest, therefore account for only a small part of the loss

(4) Reflex Trophic Effect It is known that there is a more rapid and extreme wasting in limbs immobilized for some inflammatory or traumatic lesion than for the correction of a deformity The atrophy has been shown to depend on the integrity of the afferent paths (8) This theory implies an exhaustion of the muscle by an excessive number of nervous stimuli While it may account for the greater loss of muscle which occurs in the injured limb as compared to the other limbs the total nitrogen loss is greatly in excess of that contributed by the injured limb Cuthbertson McGirr and Robertson (11) showed by actual measurement that the loss of substance from the site of injury or from the injured limb does not fully account for the wastage and that a generalized loss occurs Additional carbohydrate seems to exert a definite sparing effect on the general loss of tissue substance but does not prevent local wastage The loss of muscle in general accounts for four fifths of the total loss of body weight the reserves of carbohydrate and fat accounting for the remainder

To summarize this discussion of the metabolic response to injury following trauma, infection burns or other injury there occurs a loss of nitrogen which varies with the nature and severity of the insult The loss is caused mainly by the generalized catabolic effect of the insult but may be aggravated by the contributory effects of fever starvation disuse atrophy reflex trophic effect and actual losses of protein in the form of hemorrhage exudates and escape of plasma

studied had no fever or only a slight elevation Fever therefore, does not account for the catabolic loss of nitrogen in non febrile conditions and is only a contributory factor in febrile cases

(2) Starvation is not the explanation although by itself if prolonged it may lead to protein deficiency At the height of the catabolic period diets containing up to 5 000 calories a day are incapable of reversing the negative balance (13) In the acute infections studied by du Bois and his associates at the Russell Sage Institute the administration of a diet containing more calories than the body expended in the form of heat as measured by calorimetry failed to prevent the loss of nitrogen On the other hand in simple uncomplicated starvation, the nitrogen loss can be appreciably reduced by feeding carbohydrate and quickly stopped by giving a diet which provides adequate calories and protein Starvation, therefore does not explain the catabolic reaction, but like fever and disuse contributes its share to the loss

(3) Disuse Atrophy and Bed Rest In 1929 Cuthbertson (32) found that normal subjects in nitrogen equilibrium showed within a day or two from the beginning of bed rest involving fixation of a lower limb in a splint, a rise in the urinary excretion of sulphur nitrogen and phosphorus in that order of priority The rise was maintained fairly steadily for a varying period and then declined This loss is similar to that which occurs after injury but is of considerably smaller extent He showed further that after the period of simple disuse, operative removal of a fragment of semilunar cartilage resulted in a marked increase in the loss of nitrogen, indicating that simple disuse is not the explanation In Howard s series of cases (19 20) patients immobilized

trophic hormones are injected and in the adrenalectomized animal if adrenal cortical hormones are injected Dougherty and White (36) have shown that the number of lymphocytes in the blood is regulated by the pituitary via the adrenal cortex and that injections of pituitary adrenocorticotropic hormones or of any one of a number of adrenal cortical hormones (but not of desoxycorticosterone) will produce within a few hours an absolute lymphopenia Venning Hoffman and Browne (37) found that individuals exposed to the stress of surgical procedures excreted from three to 30 times the amount of cortin like substances that is excreted in the urine by normal men Shipley and Dorfman (38), too, demonstrated a rise in the urinary output of cortin in cases of infectious disease, after operation and after burns These findings are confirmatory evidence of increased adrenal cortical activity after injury The Alarm Reaction may therefore be considered as a response by the adrenal cortex which secretes excessive amounts of hormones which in turn produce thymic and lymphoid hypoplasia and set in motion the changes characteristic of the metabolic response to injury The adrenal cortex is stimulated to excessive activity by the corticotropic hormone of the pituitary which is itself stimulated by the injury in some as yet unknown manner After the first 48 hours the adrenals are still enlarged but have regained their lipoid granules There is an increase in the basophilic cells in the pituitary the thyroid tends to show hyperplasia, general body growth ceases and the gonads become atrophic. These changes are interpreted to mean that the pituitary slows down its production of growth and gonadotropic hormones in order to favor increased production of adrenotropic and thyrotropic hormones which are more urgently needed

from the surfaces of wounds and burns At the height of the reaction the negative nitrogen balance cannot be corrected by any dietary means presently available, but during the late catabolic period it can be minimized and in some cases prevented by very high caloric and protein intakes The catabolic response is exhibited characteristically by individuals in vigorous health and nutrition Malnourished and protein depleted subjects do not exhibit the reaction or do so only to a limited degree

GENERAL ADAPTATION SYNDROME

Following trauma operative surgery partial or complete transection of the spinal cord exposure to cold burns excessive muscular exercise, sublethal doses of various drugs, infections prolonged starvation and other types of insult there occurs a series of adaptive reactions described by Selye as the General Adaptation Syndrome (33 34 35) The symptoms and signs of this syndrome are the same for all types of injuries are independent in the nature of the damaging agent and develop in three stages

(1) The Alarm Reaction Immediately after injury experimental animals show a shock like response, followed by a counter shock phase within 48 hours The characteristic changes of the counter shock phase constitute the alarm reaction and consist of enlargement of the adrenals and disappearance of the adrenal cortical lipoids indicating increased cortical activity At the same time there is a decrease in the size of the thymus spleen and lymph nodes and a reduction in the percentage of lymphocytes in the peripheral blood The thymic and lymphoid atrophy does not occur in the absence of the adrenals or of the pituitary it does occur in the hypophysectomized animal if cortico-

reaction is catalyzed by the enzyme hexokinase and may be expressed as follows

Reaction I Glucose $\xrightarrow{\text{Hexokinase}}$ Glucose — 6 — phosphate

The reverse reaction the conversion of the metabolically active phosphorylated glucose to metabolically inert glucose is mediated by the enzyme phosphatase, and may be expressed thus

Reaction II Glucose — 6 — phosphate $\xrightarrow{\text{Phosphatase}}$ Glucose

The activity of phosphatase is independent of hormonal control but the activity of hexokinase is definitely controlled by the hormonal secretions of the anterior pituitary adrenal cortex, and islet cells of the pancreas Price Cori and Colowick (39) have demonstrated that the anterior pituitary secretes a hormone which inhibits hexokinase This inhibitory effect is accentuated and prolonged by adrenal cortical hormone and is abolished by insulin Glucose present in the blood is derived from two sources (a) absorption from the digestive tract (or parenteral injection) (b) conversion of glucose-6-phosphate to glucose (Reaction II) The blood sugar level is therefore the resultant of (a) and (b) on the one hand and of the conversion of glucose to glucose-6-phosphate (Reaction I) on the other Inhibition of the latter reaction as by insulin deficiency or by excessive pituitary or adrenal cortical activity will result in a rise in blood sugar which if permanent is diabetes mellitus It has already been pointed out that pituitary and adrenal cortical hyperactivity are characteristics of the Alarm Reaction to bodily injury It is now clear why glucose tolerance is im

(2) Stage of Resistance Upon repetition of the injurious stimuli the appearance and functions of the organs return to normal and the pituitary and adrenals no longer respond with *increased activity or do so only to a limited* degree. This corresponds to the failure of poorly nourished or protein depleted individuals to exhibit the catabolic reaction to injury This second stage of the general adaptation syndrome has therefore been termed the Stage of Resistance

(3) Stage of Exhaustion With continued repetition of injurious stimuli, the resistance of the animal eventually breaks down and its dies with symptoms and signs similar to those of the first stage The adrenals are enlarged, as in the first stage but in addition they show degeneration and necrosis of the cortical cells This stage is termed the Stage of Exhaustion. It is manifested clinically by those chronically ill and malnourished patients who have been apparently *holding their own and who suddenly with or without* additional provocation, go into a precipitous decline to a fatal termination This is a common terminal phase in patients with spinal cord injuries

METABOLISM OF THE MAJOR FOODSTUFFS

To explore further the physiological mechanisms and the clinical implications of the catabolic response to injury it will be necessary to review some of the pertinent highlights of the intermediary metabolism of the major foodstuffs

CARBOHYDRATE METABOLISM

Glucose the form in which carbohydrates are ultimately utilized, is itself metabolically inert and must be phosphorylated before it can enter into metabolic activity This

able as in starvation or when glucose cannot be metabolized because of excessive inhibition of hexokinase, as in the reaction to injury proteins and fats are called upon to supply energy The amino acids diverted for this purpose are therefore unavailable for tissue protein synthesis Since tissue build up and tissue breakdown are constantly in a state of dynamic flux a decrease in the available supply of amino acids for synthesis results in a net loss of tissue protein This explains, in part at least, the negative nitrogen balance characteristic of the reaction to injury and also the depletion of the body stores of fat Conversely the well known sparing effect of carbohydrates and fats on protein metabolism is also clarified

FAT METABOLISM

Following absorption from the gut neutral fat is deposited chiefly in the fat depots of the body These depots are no longer considered as inert structures functioning as warehouses but are now known to be very active metabolically Schoenheimer (40) has shown that when fat is absorbed, the dietary fatty acids merge with those previously present in the depots forming a mixture indistinguishable in origin There is a constant interchange of fatty acids between the depots and organs Some fatty acids are converted to others new ones are synthesized from chemical fragments derived from glucose and amino acids (Fig 1) and some are oxidized to CO_2 and H_2O The liver serves as a center for assembling and sorting fatty acids and phospholipids interconverting them manufacturing ketone bodies from them and redistributing them to the depots and tissues (41) All these reactions are normally so balanced that the total amount and structure of the fat mixture in

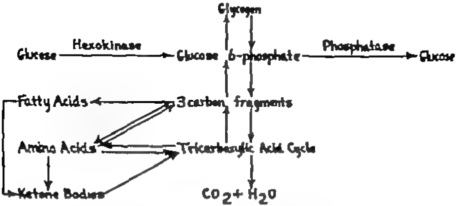
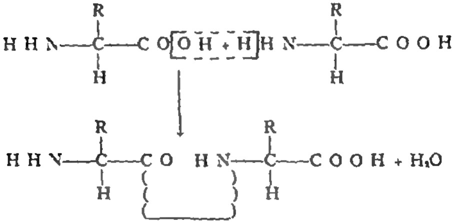


Fig. 1 Metabolic Fate of Glucose Discussion in text. (Adapted from Stetten DeWitt, Jr The Endocrine Regulation of Carbohydrate Metabolism, J.A.M.A 132 374 1946)

paired during infections after trauma operative procedures exposure, and other types of injury

Glucose-6-phosphate is further metabolized through a series of intermediate chemical steps to glycogen in one direction and to CO_2 and H_2O in the other (Fig 1) When hexokinase is inhibited, as in the reaction to injury or in diabetes mellitus glucose cannot be converted to glucose-6-phosphate, it remains metabolically inert and cannot be utilized The energy requirements must therefore be met by the proteins and fats The manner in which amino acids and fatty acids enter into the metabolic pathway leading ultimately to oxidation is indicated in Figure 1 which also shows how glycogen and glucose may be formed from these substances For example amino acid derivatives entering the tricarboxylic acid cycle may be oxidized to CO_2 and H_2O or may become converted eventually to glucose-6-phosphate which in turn forms glucose (via phosphatase) or glycogen The greater the amount of glucose which enters the pathway to oxidation the smaller the need for fatty acids and amino acids for energy purposes When glucose is unavail

form proteins they do so in a characteristic manner known as a peptide linkage This consists of a combination of the amino group of one amino acid with the carboxyl group of another amino acid the R groups remaining free and unattached In addition to the peptide link the hydrogen of the amino group shares an electron with the oxygen of the carboxyl group forming a covalent bond or bridge between them



PEPTIDE LINKAGE

It will be noted that the new product still contains free NH_2 and COOH groups each of which may combine with the COOH and NH_2 groups respectively of other amino acids Proteins are composed of numerous amino acids linked together in the manner described The reverse process in which the peptide bond is broken and amino acids liberated is one of hydrolysis Proteans proteoses peptones and peptides are substances whose structure is intermediate in complexity in decreasing order between proteins and amino acids

The manner in which amino acids are linked together is important because it represents a site of intense metabolic

depot, blood and organs remains constant. When glucose is not metabolically available because of its absence from the diet or because of excessive hexokinase inhibition, as in the reaction to injury the greatest portion of the fatty acid pool is diverted for energy purposes If fat and protein are at this time absent from the diet, the fat in the depots will rapidly disappear resulting in loss of body weight

It was stated that fatty acids are synthesized from other fatty acids and from proteins and carbohydrates Exceptions to this are the highly unsaturated fatty acids which cannot be synthesized unless either linoleic acid or arachidonic acid is supplied in the diet (40 42) These two fatty acids are thus essential or indispensable

PROTEIN METABOLISM

Proteins consist of amino acids linked together by peptide bonds supplemented by hydrogen bridges There are some 22 amino acids With the exception of proline and hydroxyproline all amino acids may be represented by the following formula

$$\begin{array}{c} R \\ | \\ \mathrm{HHN}\!-\!\!\!-\!C\!-\!\!\!-\!\mathrm{COOH} \\ | \\ H \end{array}$$

R represents a carbon chain which is different for each amino acid In glycine R represents a hydrogen atom In proline and hydroxyproline there is an imino (NH) group instead of an amino (NH_2) group and R represents part of a pyrrolidine ring All amino acids contain one or more amino (or imino groups, plus one or more carboxyl (COOH) groups When they combine with one another to

nine lysine, phenylalamine tryptophane arginine, histidine and threonine

The building up and the breaking down of the protein molecules are under hormonal control which in the normal adult maintains a balance between anabolism and catabolism Stimulation of the anabolic or inhibition of the catabolic enzymes results in a net gain of protein while inhibition of the anabolic or stimulation of the catabolic enzymes results in a net loss of protein The growth hormone of the anterior pituitary promotes anabolism and the hormones from the thyroid and adrenal cortex promote catabolism (43) In the reaction to injury the increased activity of the pituitary by its stimulation of the adrenal cortex and thyroid produces a catabolic effect resulting in a net loss of protein Whether this is due to inhibition of anabolism (24) or to increased catabalosm (29) is still a matter of dispute A part of the nitrogen loss may be explained as due to hexokinase inhibition which necessitates the breakdown of protein to supply energy

SUMMARY OF METABOLISM OF MAJOR FOODSTUFFS

It may be well at this point to summarize the chief points in this discussion of the metabolism of the major foodstuffs Glucose, amino acids and fatty acids are broken down to smaller molecular fragments or built up to form the larger molecules of the carbohydrates proteins and fats respectively The smaller fragments enter into a variety of chemical reactions which result in the interconversion of the various molecules so that the ultimate compounds are derived from all sources, with some exceptions The processes of building up and breaking down of tissue are continuous

activity During the intermediary metabolism of proteins these linkages are constantly disrupted and united, amino groups being introduced or removed at an extremely rapid rate (40) Amino groups derived from amino acids recently absorbed from the intestines enter into these chemical changes as rapidly as do those derived from the break down of tissue proteins the result being that amino acids of dietary origin soon become indistinguishable from those of tissue origin and the tissue proteins are composed of an ever changing complex of amino acids derived from all sources The chemical reactivity of proteins in metabolism is not restricted to their nitrogen (amino) groups but the carbon chains too participate in these rapid chemical interchanges The carbon chains may be derived from carbohydrate or fatty precursors as well as from proteins Referring again to Figure 1 it is evident that there exists a common metabolic pool of highly reactive substances and molecular fragments derived from different sources which contribute indistinguishably to the metabolism of proteins, carbohydrates and fats

As in the case of the fatty acids there are some amino acids which cannot be synthesized, and must be supplied in the diet. If not, tissue breakdown is increased in order to supply the pool with these amino acids Since some of them enter into reactions which are irreversible there is a net loss of protein, or negative nitrogen balance unless these essential or indispensable amino acids are replaced in the diet and in adequate amounts Their indispensability refers only to the fact that they must be present in the diet and does not imply that they have more important functions than dispensable amino acids There are ten essential amino acids Valine, leucine isoleucine, methio-

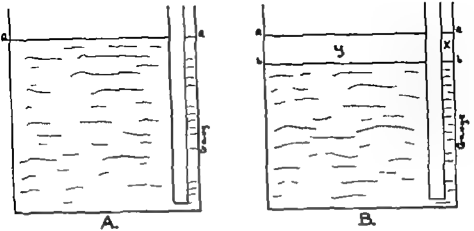


FIG. 2 Diagram to illustrate relation between changes in levels and total quantities of fluid

A. Original quantity in tank.

B A small drop in level from a to b in the gauge (x) represents the loss of a considerably greater amount of fluid in the tank (y)

appeared promptly from the circulation without a corresponding loss in the urine

Because of this balance and because the total amount of protein in the viscera and skeletal tissues is so vastly greater than the amount of protein in the circulation quantitative changes in tissue proteins will be reflected by changes in plasma proteins in somewhat the same manner as a change in the amount of water in a storage tank is reflected by the level in the gauge Referring to Figure 2 it is obvious that a slight fall in the level in the gauge represents a considerable loss of water in the tank Weech (46) found that in protein deficiency induced in dogs by a protein deficient diet, one fifth of the total protein loss was contributed by the circulation and four fifths by the other tissues Elman (47) has calculated that a reduction of one gram of cir

and rapid, and most of the reactions are mediated by enzymes under endocrine control. Particularly important for this discussion are the roles of the anterior pituitary and the adrenal cortex. These organs secrete certain hormones which when present in excess result in a net increase in protein catabolism. This is due to two mechanisms. One is a direct inhibition of protein anabolism or stimulation of protein catabolism. The other is an inhibition of hexokinase activity thereby interfering with the utilization of glucose and resulting in an increased destruction of protein for the production of energy.

PLASMA PROTEINS AND TISSUE PROTEINS

The concept of body structure according to which adult tissue remains relatively constant in composition and structure except for wear and tear is no longer tenable. Schoenheimer (40) has shown that all tissues are active metabolic structures in which chemical synthesis and breakdown are constantly going on. These chemical activities involve circulating plasma proteins, including circulating antibodies, in the same manner as tissue proteins. Whipple and his collaborators (44) have advanced the theory of a dynamic state of equilibrium between the proteins of the blood and those of the tissues. The body protein stores, protein synthesis and protein breakdown are in a balanced or steady state of dynamic equilibrium. Proteins can pass readily from plasma into tissue cells, and the reverse, without loss of nitrogen (45). The net effect is an apparent qualitative and quantitative constancy of plasma and tissue proteins. Additional evidence for this concept is provided by Leutscher (50) and by Metcalf (51) who showed that protein given intravenously in the form of serum, plasma, or albumin dis-

equal facility under conditions of stress The liver, for example, loses protein more readily than do the other organs Addis (48 49) found that the livers of albino rats lost 20 per cent of their original protein content during a two-day fast as compared with four per cent for all the other organs combined During a seven-day fast the liver lost 40 per cent of its original protein while muscle skin and skeleton lost 8 per cent However since the total bulk of the skeletal tissues is so much greater than the viscera, 62 per cent of the total loss was contributed by the muscles skin and skeleton as compared with 16 per cent for the liver With regard to blood proteins in protein deficiency, in terms of the original quantity present serum albumin suffers the greatest depletion, hemoglobin somewhat less and serum globulin the least (46) Recent electrophoretic studies have shown both in animals and man, that in protein depletion of sufficient severity to be reflected in the plasma proteins the greatest decrease occurs in the albumin and a somewhat smaller decrease in the globulins except the alpha globulins which resist depletion (52) During regeneration after deficiency the synthesis of hemoglobin is favored over plasma proteins by as much as two or three to one (45)

The reasons for the relatively normal plasma protein concentrations in depleted patients with spinal cord or other severe injuries have been discussed It is not clear why the depletion is reflected so much more in hemoglobin Total plasma proteins are reduced about 7 per cent, while total circulating hemoglobin is reduced 37 per cent Since competition for available protein building materials favors hemoglobin production other factors such as sepsis and inhibition of hematopoiesis must play important roles

culating plasma albumin represents a loss of 30 grams of tissue protein Thus a subject with a plasma albumin con centration of four grams per 100 cc and a plasma volume of 3 500 cc would have 4 x 35 = 140 grams of circulating albumin. A reduction in the concentration to 3 5 gms per 100 cc without any change in plasma volume would mean a reduction in circulating albumin to 123 grams (3 5 x 35) — a loss of 17 grams If each gram of plasma albumin represents 30 grams of tissue protein, such a reduction of plasma albumin from four grams per 100 cc. to 3 5 grams per 100 cc. is indicative of a loss of 17 $\times$ 30 = 510 grams of tissue protein which in terms of muscle represents (510 $\times$ 5) 2 5 Kgm In the light of the tremendous weight losses suffered by patients with severe trauma, the ratio of tissue protein loss to plasma protein loss of 30 to one may have to be revised upward. Ling and Sprinz (3) found an average total circulating plasma protein of 204 grams in 20 severely depleted patients as compared with an average of 220 grams in 50 normal adults This is a loss of 16 grams of plasma protein, which if the ratio of 30 to one were correct, would indicate a loss of only 2 4 Kgm of muscle tissue Actually these patients had lost 23 Kgm (50 pounds) which with a liberal allowance for loss if adipose tissue, represents a much greater ratio than 30 1 The unreliability of the plasma protein concentration as an index of the degree of protein depletion in man is therefore obvious A tremendous degree of tissue wasting must occur before it will be reflected in the total plasma protein level much less in the concentration which is also affected by changes in plasma volume

The concept of a dynamic state of body constituents does not imply that all proteins are synthesized or destroyed with

equal facility under conditions of stress The liver, for example loses protein more readily than do the other organs Addis (48 49) found that the livers of albino rats lost 20 per cent of their original protein content during a two-day fast as compared with four per cent for all the other organs combined During a seven-day fast the liver lost 40 per cent of its original protein while muscle skin and skeleton lost [illegible] per cent However since the total bulk of the skeletal tissues is so much greater than the viscera, 62 per cent of the total loss was contributed by the muscles skin and skeleton as compared with 16 per cent for the liver With regard to blood proteins in protein deficiency in terms of the original quantity present serum albumin suffers the greatest depletion hemoglobin somewhat less and serum globulin the least (46) Recent electrophoretic studies have shown both in animals and man, that in protein depletion of sufficient severity to be reflected in the plasma proteins the greatest decrease occurs in the albumin and a somewhat smaller decrease in the globulins except the alpha globulins which resist depletion (52) During regeneration after deficiency the synthesis of hemoglobin is favored over plasma proteins by as much as two or three to one (45)

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PROTEIN DEFICIENCY AND EDEMA

In 1895 Starling showed that the colloid osmotic pressure of the plasma was proportional to the concentration of plasma proteins and he advanced the theory that edema could be produced by a decrease in the colloid osmotic pressure Because its molar concentration is much higher than the other plasma proteins, albumin accounts for the major portion of the colloid osmotic pressure During World War I edema was commonly observed in areas where people were forced to subsist for long periods of time on protein deficient diets In World War II edema was present in a large percentage of men who were semi starved for a long time in Japanese and German prison camps Keys (65) found edema in his starving subjects and Benedict s (64) case showed water retention after the 11th day of the fast. On the other hand our severely depleted traumatized patients did not show edema, but the increased amount of extracellular fluid was an indication of a state of preclinical edema. For edema to become clinically evident at least ten pounds of water must be retained Weech s experimental data seem to indicate that the entire process of protein depletion is accompanied by gradual fluid retention (67) This would seem to be in accord with the clinical findings If the traumatized patients had been permitted to continue in their depleted state for a longer period of time, the incidence of edema would undoubtedly have been higher It will be noted that the repatriated patients who showed edema had been starved for from seven to 17 months

PROTEIN DEFICIENCY AND WOUND HEALING

There is a latent or lag period in the healing of wounds which is the interval between the receipt of the wound and

the beginning of tensile strength (53) During this period the processes involved in wound repair may be affected by various conditions among them the nutritional state of tissues Clark is quoted (53) to the effect that experimentally a high protein diet eliminates the lag period, while a high fat diet prolongs it Tissue edema, which may result from hypoproteinemia, definitely delays the onset of fibroplasia Thompson, Ravdin and Frank (54) studied the effect of hypoproteinemia on wound disruption in dogs They noted disruption of the wound or failure to heal in 72 per cent of their animals and found edema at the site of the incision as late as seven to 14 days after operation In the biopsy sections taken 14 days after operation fibroblasts were present but in decreased numbers indicating defective fibroplasia. Protein deficiency is not the only cause of wound disruption It has been recognized for at least two centuries that wounds are slow to heal in scurvy Wolbach (55) has shown that this is due to failure of collagen formation and that it can be corrected by the administration of vitamin C. Lanman and Ingalls (56) were able to produce rupture of abdominal wounds of scorbutic animals with about one-third the pressure required in normals Histological examinations revealed poor production of collagen in the scar Hartzell (57) found in cases of wound disruption that both the plasma vitamin C and the plasma protein levels were decidedly lower than normal Retardation of wound healing is thus one of the consequences of vitamin C or of protein deficiency With regard to the healing of fractures Kernwein (58) and Rhoads and Kasinskas (59) showed that ossification of bony callus is retarded in protein deficiency Here too the absence of vitamin C may play a role, as Bourne claims that the activity of both en-

dosteum and periosteum in the repair process of bone is diminished in vitamin C deficiency (60)

PROTEIN DEFICIENCY AND DECUBITUS ULCERS

Of the factors concerned in the development of bed sores local pressure is obviously one of the most important since decubitus ulcers develop at pressure points It is known that pressure applied locally to even normal tissues for a sufficient length of time can cause local necrosis In protein deficient tissues it apparently requires a smaller amount of pressure, or the same pressure for shorter periods of time to cause necrosis (61) The rapidity with which decubitus ulcers develop in patients with spinal cord injuries is readily explained on this basis With improvement in the nutritional state and repletion of the body proteins the ulcers tend to heal. Conversely failure to improve the nutritional state is associated with persistence or recurrence of the ulcers regardless of the type of treatment

PROTEIN DEFICIENCY AND RESISTANCE TO INFECTION

Resistance to infection depends on a great number of variables among which are included a variety of specific and non specific antibodies It is now generally recognized that these immune antibodies are proteins and in the circulation are constituents of the gamma globulins of the plasma. These proteins partake of the same chemical reactions as other tissue proteins with respect to the dynamic state of body constituents Body protein deficiency may therefore be associated with a decrease in antibodies and thus in decreased resistance to infection. Cannon (62, 63) has shown

that protein depletion leads to a failure to produce antibodies In protein deficiency induced by an inadequate diet the production of antibodies was reduced to from one third to one-fifth of normal This explains why malnutrition is so commonly complicated by overwhelming infection In six fatal cases of traumatic transverse lesions of the spinal cord Rappaport reported as common features extreme emaciation, severe anemia, and a spreading inflammation regardless of anatomic barriers, indicating a loss of general and local resistance On the other hand, in patients who survive it is commonly observed that as the nutritional state improves the incidence and severity of complicating infections tends to decrease

PROTEIN DEFICIENCY AND EMOTIONAL REACTIONS

It would be hazardous to blame nutritional deficiency for the mental and emotional reactions manifested by patients with spinal cord injuries but that it does contribute to their production is probably true Benedict s (64) starving man developed gradually increasing depression as a prominent symptom in his study of experimental human starvation. The improvement in mental attitude of paraplegic patients as their nutritional state improved has been mentioned Since the deficiency in these cases and in normal starving subjects is predominantly protein, it is probable that at least some of the symptoms are due to lack of protein Thiamine deficiency also produces psychologic abnormalities (66) but there is little evidence of such deficiency in depleted traumatized patients Regardless of the degree to which protein deficiency is responsible for the mental abnormalities it is certainly true that the mental

abnormalities contribute to the malnutrition. The irritability resentment and depression which these patients manifest add greatly to the problems of dietary management.

URINARY CALCULI AND THE METABOLIC REACTION TO INJURY

A high incidence of urinary calculi in patients with fractures has been recognized for many years Goldstein and Abeshouse (68) have reviewed the literature and state that the earliest association of spinal cord fracture and urinary lithiasis was reported by Costello in 1833 Muller in 1895 found renal stones in 10 per cent of cases of fractured vertebrae and also noted that the symptoms of stone were not manifested before three months after the injury After World War I the association between bony injury and renal lithiasis became more prominent and was attributed at first to bony suppuration (69) and later to prolonged recumbency Wilson (70) reported 23 cases of renal colic and hematuria occurring in 150 cases of fractured femur in casualties of World War I All of these patients had been recumbent for periods varying from three to 12 months or more A number of reports have appeared since stressing the importance of prolonged recumbency as etiologically related to stone formation (71 72 73 74 75 76 77 78 82) The high percentage of urinary calculi in World War II patients with injuries necessitating prolonged rest in bed seems to confirm the etiological importance of prolonged recumbency The reported incidence of stones in these patients may vary considerably depending on the time elapsed from the injury The longer the interval the greater will be the number of calculi found In patients with spinal cord injuries the incidence of stones may be 40 per cent or higher after

three or more months Cuthbertson (32) noticed a tendency toward an increased excretion of calcium due to immobilization alone Howard too observed small increases of urinary calcium when healthy patients without fracture were immobilized in casts (79) However the chief underlying cause is the alteration of calcium metabolism induced by the injury, a catabolic reaction to trauma

Urine is a supersaturated solution of crystalloids maintained in solution by colloids There is a definite quantitative relationship between the colloids and crystalloids and any substantial alteration in this relationship will lead to precipitation and calculus formation While infection trauma, anatomical abnormalities and other causes may upset the crystalloid-colloid balance, this discussion will be confined to those factors which cause an increase in the crystalloid content of the urine, specifically the calcium content That hypercalcinuria is associated with stone formation is well recognized Stones of recumbency have been attributed to increased calcium excretion caused by recumbency as such

Howard (79) investigated the calcium metabolism in 17 patients immobilized in leg and body casts Four patients were studied before and after femoral osteotomy the others had fractures The patients were well nourished A steady rise in the urinary calcium excretion occurred in all cases The maximal excretion was reached about one month after the injury was maintained at this level for 30 to 60 days and then began to fall slowly After osteotomy the pattern of excretion was similar but the plateau was reached earlier and was maintained for a shorter period Just as during the height of the protein catabolic responses the feeding of a high caloric high protein diet failed to alter

the nitrogen excretion, so during the plateau period of the calcium response large shifts in dietary calcium resulted in inconsequential changes in urinary calcium It should be noted that the maximal excretion of calcium was reached in every case at a time when the protein catabolic reaction was subsiding

Howard s patients were well nourished individuals and therefore exhibited the typical catabolic response to injury No data are available relative to the calcium response of mal nourished individuals However indirect evidence is avail able which indicates that their calcium metabolism behaves like their protein metabolism i e., the catabolic response is minimal or absent The evidence consists of the low incidence of renal calculi in patients with chronic pulmonary tuberculosis In 39 autopsies performed in a tuberculosis hospital renal calculi were found in only one case This patient had been bedfast for only a very short time before death The vast majority of the other cases had been confined to bed for many months Auerbach (80) on the basis of his experiences in a 1900 bed tuberculosis hos pital states that the incidence of urinary calculi found at autopsy is less than one percent Most patients who succumb to chronic tuberculosis have been ill for a long time, are generally in a poor nutritional state and have usually been recumbent for months prior to death

The behavior of calcium metabolism after injury thus bears a close resemblance to protein metabolism, except for the time relationship The resemblance is strengthened by the fact that pituitary hyperactivity is known to cause abnormalities of calcium metabolism manifested by increased excretion (81) It will be recalled that injury stimu lates pituitary activity The explanation for the late calcium

response is obscure but it may be related to differences between the rate of enzyme activity in a dense structure like bone and the rate in soft tissues The delayed response is responsible for the long interval between the injury and the development of stones

Howard in his fracture cases noted that the administration of dietary calcium in the form of milk failed to increase the urinary calcium This has a therapeutic implication — namely that the administration of milk during the calcium catabolic period will not increase the tendency to calculus formation Howard also found that alkalinizing the urine had no effect on the calcium output Acidifying the urine might theoretically decrease the precipitability of the calcium, but with the tremendous calcium exertion, it is doubtful whether this would be of practical value In spinal cord cases the anorexia and aversion to food being so great, all dietary efforts must be directed toward a high caloric and protein intake without regard to the effect on the urinary pH The prescribing of acid ash diets would only add to the difficulties in feeding these patients Acidifying the urine with drugs might readily upset their precarious appetites and interfere with their alimentation

THE ROLE OF VITAMINS

The paucity of signs of vitamin deficiency in the wasted patients with spinal cord injuries has been commented on and contrasted with the high incidence of such signs in repatriated prisoners of war There are three reasons for the difference

(a) The administration of vitamins
(b) The duration of undernutrition
(c) The degree of metabolic activity and nature of the diet.

(A) ADMINISTRATION OF VITAMINS

An obvious reason for the difference is the alacrity with which vitamins are prescribed and taken in American medical practice. Patients in American hospitals have ready access to all sorts of vitamin preparations and can hardly avoid taking them while malnourished prisoners in enemy hands are not so well situated.

(B) DURATION OF UNDERNUTRITION

The vitamin stores of the body are usually so great that it requires a long period of deprivation before they are exhausted. Keys (65) found no signs of vitamin deficiency in his starving subjects who lost one fourth of their body weight in six months. Wald, Brouha and Johnson (83) were able to keep five normal subjects on a low vitamin A diet for six months without producing signs of deficiency. In another study signs of deficiency appeared within a period of 188 days after the institution of vitamin A deficient dietary regimen (84). Thiamin deficiency may similarly not become apparent for some time. Wilder (66) reported the appearance of clinical effects of a thiamin deficient diet in from 93 to 196 days. With regard to vitamin C, scorbutic petechiae did not appear until the 152nd day in the study reported by Lund and Crandon (85).

(C) *DEGREE OF METABOLIC ACTIVITY* AND NATURE OF THE DIET

Of great importance is the relationship of some of the water soluble B vitamins to metabolism, particularly to carbohydrate metabolism. Thiamin acts as a coenzyme to carboxylase, forming an enzyme system which is necessary for the breakdown of pyruvic acid. Riboflavin combines with phos-

phoric acid and protein to form a coenzyme which participates in the hydrogen transfer in energy metabolism while nicotinic acid functions as a component of two coenzymes which are also concerned with the oxidation of carbohydrates The exact roles played by the other members of the B complex in metabolism have not been fully clarified but they are probably also related to enzyme activities A reduction in the total diet or in the amount of carbohydrate ingested reduces the requirement for the enzymes concerned in the oxidation of glucose and thereby lessens the need for the vitamins A lowered metabolic rate has a similar effect Conversely an increase in total calories or in carbohydrate intake or in total metabolism will increase the vitamin requirement Physical activity which increases total metabolism, is one of the factors which increase the requirement of the B vitamins

Applying these principles to the patients with spinal cord injuries the low incidence of clinical signs of vitamin deficiency may be attributed to their semi starvation, their inactivity and their lowered metabolism after the initial period of intense metabolic activity had waned and mal nutrition supervened On the other hand the war prisoners were forced to work hard so that their vitamin require ments were not materially lowered The duration of under nutrition in the prisoners varied up to four years while in the paraplegics few remained malnourished after several months It is significant that the clinical signs of deficiency noted were chiefly those of the B complex

PRACTICAL CONSIDERATIONS

The aims in treatment are to prevent minimize and re place the wasting of body tisse In the present state of

knowledge, prevention does not seem to be feasible, unless the claims of Croft and Peters for methionine are confirmed in man But it is practical and desirable to keep the losses down and it is imperative to replace them when protein deficiency ensues The treatment consists of the intake of food adequate in all essential nutrients and particularly rich in calories and protein The chief stumbling block to the carrying out of this treatment is anorexia or lack of appetite

ANOREXIA

Appetite (86) has been defined as a conditioned state of consciousness based on the memory of pleasant experiences which are associated with eating and drinking and which create a desire for food There is some evidence that appetite is not entirely a mental phenomenon but that it may be related to gastric tone In those diseases in which anorexia is a prominent feature gastric tone is often low while in those characterized by excessive appetite the tone is frequently high (87) Hunger which is to be differentiated from appetite is a gastric sensation of discomfort or actual pain due to strong peristaltic contractions arising in the stomach when it is empty or nearly so (88) Since food intake is dependent on appetite and hunger i e on mental state, gastric tone and gastric motility factors which depress these functions will decrease food intake Mental depression, fever pain local gastro-intestinal abnormalities and reflexes from other diseased organs inhibit gastric tone and motility Most of these are present in varying degree in patients with spinal cord injuries and contribute to the production of anorexia and the inhibition of hunger contractions A state of semi starvation is thus induced adding to the catabolic loss of weight Starvation itself results in mental depres-

sion (64, 65) and diminution in appetite and hunger contractions thereby producing a vicious cycle which can be broken only by the most vigorous therapeutic measures

Overloading an atonic stomach may produce gastric distention nausea or vomiting Since the emptying time of such a stomach is prolonged, the total volume of food and liquid which can be comfortably ingested is limited Too much fat in the ingesta increases gastric retention and thereby aggravates the problem of supplying a rich diet in a small bulk On the other hand there is no evidence that the digestive and absorptive processes are impaired

INSULIN

The use of insulin for the purpose of putting weight on undernourished individuals has been reported on favorably by a number of observers (89 90 91) The rationale for its use is its ability to promote appetite and create hunger by stimulating gastric contractions (92) This effect is lost when the stomach becomes atonic because of vitamin B deficiency It is therefore questionable whether the atonic stomachs of severely depleted patients would respond to small doses of insulin The use of large doses is fraught with danger because of the possibility of severe hypoglycemic reactions Most of the clinical studies on the effect of insulin in non-diabetic malnutrition have been on otherwise normal subjects and not enough is really known about its value in the chronically ill. However in the early stages of the catabolic response to injury when the pituitary is hyperactive the use of insulin may be of distinct value in counteracting the inhibition of hexokinase and thereby decreasing to some extent the destruction of protein The daily administration of 10 to 20 units of protamine zinc insulin during the first

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week or two after injury is suggested for this purpose If used daily blood sugar determinations are indicated. As the catabolic reaction wanes the dosage of insulin should be decreased and then discontinued

The nutritional care of patients with traumatic lesions of the spine falls naturally into two periods treatment during the early catabolic phase, and treatment during the late catabolic and the anabolic phases

TREATMENT DURING EARLY CATABOLIC PHASE

During this period all of the dietary nitrogen and all of the nitrogen of protein hydrolysates and of amino acid mixtures whether administered orally or parenterally will be quantitatively excreted regardless of the caloric intake The only exceptions are intravenosly administered plasma proteins The therapeutic indication is therefore to administer sufficient amounts of whole blood or plasma to replace the wasted nitrogen, together with enough calories in the form of carbohydrate to meet the energy requirements Nitrogen losses during this period usually amount to from 12 to 20 grams a day equivalent to from 75 to 125 grams of protein respectively (10) In some cases the loss may be as high as 35 grams of nitrogen equivalent to 218 grams of protein. The amount of plasma required may be figured at about two liters a day for the average patient, each liter containing from 60 to 70 grams of protein Whole blood contains a little more than half of this amount of protein per liter and so is uneconomical to use However its superiority to plasma in the treatment of shock indicates its use immediately after the injury Since the catabolic reaction does not

begin for two or three days whole blood should be used during this period for the treatment of shock, followed by the use of plasma from the second or third day until the peak of the catabolic period is over, which for practical purposes may be figured at about the tenth day

During this time the patient should be encouraged to consume as much food as possible in order to provide for his caloric needs Vigorous dietary therapy is not yet indicated but the intake should be sufficient to eliminate the extra nitrogen wasting due to starvation During the first week the well nourished patient has enough fat in his depots to supply most of his caloric needs if a certain minimum amount of carbohydrate is supplied (25) How low this minimum can be is not definitely known but Elman (93) *suggests 100 grams a day for a 70 Kg adult as a practical* guide There is no contraindication to the ingestion of more food including proteins and fats if the patient is willing to do so The carbohydrate and other foods should be taken by mouth if at all possible, since the intravenous routes will be monopolized by the transfusions

An objection to the use of plasma is the possibility of the development of homologous serum hepatitis This must be weighted against the value of a decrease in morbidity and improvement of surgical risk incident to the diminution of tissue loss Another possible disadvantage in the use of plasma, as pointed out by Elman (84) is the fact that one liter of citrated plasma contains nine grams of sodium chloride and 5 grams or more of sodium citrate The average salt requirement of a sick patient is about 10 grams and is increased in the presence of considerable vomiting and exudation (85) Two liters of plasma a day will supply about 28 grams of salt which may prove harmful if continued

for more than a few days in those cases in which the salt requirement is not excessive

TREATMENT DURING THE LATE CATABOLIC AND EARLY ANABOLIC PHASES

Most of the practical therapeutic difficulties are encountered during this period Anorexia is usually marked and the patient is irritable and uncooperative while his caloric and protein requirements are unusually high The diet must provide from 3 500 to 5 000 calories and not less than 150 and usually 200 to 250 grams of protein a day To appreciate the magnitude of this problem it should be noted that the *Food and Nutrition Board of the National Research Council* recommends for a normal active man of 70 Kgm 2 500 to 4 500 calories and 70 grams of protein a day The average well balanced American diet contains about 100 grams and the healthy American soldier during World War II consumed about 130 grams of protein a day

The high protein foods are meats (including fish and poultry) eggs and dairy products Meats contain about 20 per cent protein more or less and an average serving of one fourth of a pound (100 grams) provides approximately 20 grams of protein An egg contains about 6 grams of protein Depleted patients after severe trauma with their marked aversion to food and their small gastric capacity for bulk, simply cannot ingest sufficient meat to supply them with their large protein requirements Even when they try to cooperate they often do not have the energy to chew on solid food

The surprisingly small caloric and protein intakes of all types of patients in the average hospital has been commented on by a number of authors and was noted in our patients

Some who claimed to be eating well and who were supported in their claim by the ward nurses, were found to consume less than 1 000 calories and about 50 grams of protein when carefully checked There are a number of reasons for this in addition to anorexia and small gastric capacity Hospital foods are too often prepared without proper culinary resourcefulness, and are served cold and unattractively It might be well for hospitals to develop the art of serving food to patients with the same care that most first-class hotels provide in room service.

The following test was performed to determine how much protein in the form of ordinary food a reasonably cooperative hospital patient could be expected to consume A group of ten chronic orthopedic cases was selected Every member of the group was moderately active about the ward, showed no evidence of malnutrition had a good appetite, and was at least of average intelligence These patients were given a choice of a variety of foods to please each one individually They were instructed and urged to eat as much protein as possible and a special dietitian was assigned to help select prepare and serve the food. The dietary intakes were carefully checked for a week. The test was first performed during hot weather and the average protein intake per patient per day was 110 grams It was repeated the following winter and the average rose to 150 grams These patients were cooperative, were not very sick, and had no anorexia could chew their food, and their diets were closely supervised and carefully prepared How much then can the average patient be expected to consume if he is very ill has an aversion to food has a small stomach capacity and is given food which is unappetizing?

The answer to the problem is the preparation of a

for more than a few days in those cases in which the salt requirement is not excessive

TREATMENT DURING THE LATE CATABOLIC AND EARLY ANABOLIC PHASES

Most of the practical therapeutic difficulties are encountered during this period Anorexia is usually marked and the patient is irritable and uncooperative while his caloric and protein requirements are unusually high The diet must provide from 3 500 to 5 000 calories and not less than 150 and usually 200 to 250 grams of protein a day To appreciate the magnitude of this problem it should be noted that the *Food and Nutrition Board of the National Research Council* recommends for a normal active man of 70 Kgm 2 500 to 4 500 calories and 70 grams of protein a day The average well balanced American diet contains about 100 grams and the healthy American soldier during World War II consumed about 130 grams of protein a day

The high protein foods are meats (including fish and poultry) eggs and dairy products Meats contain about 20 per cent protein more or less and an average serving of one fourth of a pound (100 grams) provides approximately 20 grams of protein An egg contains about 6 grams of protein Depleted patients after severe trauma with their marked aversion to food and their small gastric capacity for bulk, simply cannot ingest sufficient meat to supply them with their large protein requirements Even when they try to cooperate they often do not have the energy to chew on solid food

The surprisingly small caloric and protein intakes of all types of patients in the average hospital has been commented on by a number of authors and was noted in our patients

three to four quarts a day are consumed When the caloric needs are unusually great formula No 5 or No 6 should be used but because of their high fat content diarrhea occasionally results This can be avoided or minimized by starting with a low fat formula and introducing the richer preparation gradually Various combinations may be prescribed as for example two quarts of No 4 during the day and one quart of No 6 towards evening Giving the latter at night allows more time for gastric evacuation which may be retarded by the high fat content Such a combination contains 284 grams of protein 123 grams of fat and 3 600 calories Patients who are unable or unwilling to swallow should be fed by gavage The formulas are admirably suited for this purpose They can be injected into the tube in frequent small amounts to avoid gastric distension or they can be administered by constant slow drip Ascorbic acid, 100 mgm should be added when no other source of vitamin C is furnished

As the patient s nutritional state improves and he evinces a desire for solid food meats fish poultry eggs and cheeses are gradually introduced, together with non protein foods A careful check must be kept of the actual intake of protein and calories As the intake becomes substantial the amounts of formula are gradually reduced until eventually the patient is eating four regular meals including one at bedtime with milk or milk formula in between Orange juice and other citrus fruit juices should be served during or at the end of a regular meal to avoid the diminution of appetite which may occur if taken between meals Milk or milk formula when used as a dietary supplement should be offered about one hour after meals to avoid interference with the following meal

food which is attractive to most people and in relatively small bulk, is rich in calories and proteins and contains adequate amounts of other essential nutrients Such a food can be prepared by the use of milk, milk proteins egg proteins, soluble carbohydrates and flavoring These preparations can be made to suit the individual patient s taste and the content of protein fat or carbohydrate can be varied to meet changing needs They are almost complete foods being deficient chiefly in vitamin C and iron, and if much carbohydrate is added in thiamine These deficiencies can readily be met by supplements

The milk formulas outlined below have been found useful in the treatment of malnutrition from a variety of causes and in the treatment of conditions requiring high protein intakes As outlined, the formulas show not only the ingredients and the carbohydrate protein and fat content but also the content of calcium phosphorus sodium and chloride It will be noted that the protein varies from 70 to 95 grams per quart, and the fat from 2 to 77 grams Whole milk alone contains about 35 grams of protein and 40 grams of fat In hospital practice it is convenient to have some such set of formulas which can be prescribed by number, avoiding the possibility of overburdening the diet kitchen The formulas are prepared daily and sent to the ward in a separate bottle for each patient The ward nurse adds sugar and vanilla, chocolate or other flavor depending on the individual s taste These preparations must be kept refrigerated and handled with the care required for all milk products

Nearly all patients will tolerate from the start two quarts of formula No 3 or No 4 daily This will provide 140 and 190 grams of protein and 1 470 and 2 050 calories respectively The amount is gradually increased until from

High nitrogen intakes can be provided by the oral use of protein hydrolysates However they possess little or no advantages over milk preparations are more expensive, and when given in concentrated form and large doses, have a most disagreeable taste They induce nausea vomiting and diarrhea in many patients The nausea and vomiting have been attributed to bacterial contamination (96) When employed they must be mixed with carbohydrate and for prolonged use with fat to provide sufficient calories They do not represent nearly as complete a food product as concentrated milk mixtures However they may be used to advantage in those instances where the digestion is disturbed in allergies and when because of persistent nausea and vomiting food must be introduced by Miller Abbott tube directly into the jejunum (97) When using hydrolysates or amino acid mixtures as the chief source of nourishment, vitamin supplements should be added The most important are Thiamine 10 mgm riboflavin five mgm niacin, 20 mgm ascorbic acid, 100 mgm

Mixtures of amino acids have recently been prepared which are capable of supplying the protein nitrogen requirements for long periods of time These mixtures contain unnatural as well as natural forms of amino acids The unnatural isomers are not utilized metabolically but are apparently non toxic (98) Amino acid mixtures are utilized as well as or better than hydrolysates by all routes of administration but neither is utilized orally as well as natural foods (98)

In conclusion, the solution of the problem of supplying the essential nutrients in sufficient quantity to depleted patients with traumatic injuries of the spine requires unyielding patience, perseverance and ingenuity

PROTEIN HYDROLYSATES

The use of protein hydrolysates has become increasingly popular during the past few years There is no indication for the intravenous use of these preparations immediately after trauma since the nitrogen content is excreted quantitatively during the height of the catabolic reaction. Later most patients can be induced to take nourishment by mouth It is practically impossible to supply sufficient nutrient solely by the intravenous route A liter of a five per cent solution of hydrolysate plus five per cent glucose furnishes 50 grams of hydrolysate, equivalent to about 40 grams of protein, and 50 grams of glucose for a total of 360 calories Three liters a day which is practically the limit for intravenous volume, would provide only 1 080 calories However the intravenous route may be used to supplement oral feeding The most extensively used preparation and the one which has given the most satisfactory results is Amigen an enzymatic hydrolysate of casein and pork pancreas Untoward reactions mostly pyrogenic or allergic often occur following intravenous administration

Protein hydrolysate solutions constitute excellent bacterial culture media Extreme care must be exercised in preparing them for use and the most rigid aseptic technique be employed in those cases where the solution is to be mixed with glucose A fatal case of sepsis caused by the administration of a contaminated solution has been observed by the author The contamination occurred at the time of the addition of glucose to the hydrolysate Similar staphylococci were cultured from the patient s blood and from the remainder of the solution the injection having been interrupted when the patient developed a chill

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complications that will arise and have not been presented here Many of the common associated injuries such as extensive soft tissue wounds and compound fractures of the long bones are handled by a fairly uniform plan of treatment and will not be discussed The prevention and treatment of decubitus ulcers and genito-urinary tract pathology is discussed elsewhere

EARLY ASSOCIATED INJURIES

As in any other traumatism shock and acute blood loss must be anticipated and promptly treated In general the use of whole blood when available, is preferable to plasma albumin or other substitutes in the treatment of the severely injured group; How long shock therapy is to be continued before surgery is begun will depend on the nature of the injury Active bleeding may require early intervention and can be considered an adjunct to the usual shock treatment Shock therapy must be continued with or without surgery until physiologically adequate circulation and respiration are attained

The cases having penetrating and perforating wounds of the chest and abdomen in addition to the spinal cord injury will require initial treatment of these the chest wound usually receives priority if surgical treatment is indicated The improvement in respiratory efficiency is a supplement of the shock therapy and decreases the risk of further major surgical procedures The abdominal wounds are in most instances handled before the spine injury A spinal cord injury must, however be recognized and constantly considered in the treatment of the patient it should receive adequate treatment as early as compatible with his condition

Chapter V

ASSOCIATED INJURIES AND COMPLICATIONS

WILLIAM C. WARD M D

INTRODUCTION

The large number of injuries to the spinal cord and cauda equina observed in World War II has called attention to many complications which occurred only in isolated cases during peacetime The group of war wounds consisted for the most part of shell fragment and bullet wounds although some occurred in automobile accidents and in falls Most of the additional injuries and complications are handled in the same manner as if a spinal cord lesion has not occurred It is nevertheless necessary to evaluate the patient in terms of all his injuries and to propose a plan of treatment designed to handle the combined conditions with a maximum of safety and with a minimum of residuals to interfere with later rehabilitation The extent of this rehabilitation will depend in a large measure on the prevention and treatment of the early and late complications The physician called upon to supervise the care of these patients must have some understanding of the various medical and surgical specialties and an appreciation of the need for certain highly skilled specialists to aid and advise in the handling of the especially difficult complications

The daily needs of these patients extend beyond the scope of any one specialty They are undoubtedly many

bodies are removed from the lung with a lower percentage of poor results after the acute process of wounding is past i e three or four weeks after wounding They have recom mended early thoracotomy in wounds of the diaphragm and in tension pneumothorax not controlled by catheter drain age

An occasional patient with wounds of both pleural ca vities and a bilateral pneumothorax will require prompt as- piration or watertrap drainage for survival This has been ob- served in simple compression fractures of the thoracic spine with associated bilateral rib fractures

An adequate means for aspiration of the air passages is essential in the care of all extensive chest wounds Inter costal nerve block either preoperatively or postoperatively to relieve pain in penetrating wounds of the chest may result in considerable improvement in respiratory efficiency

THORACO ABDOMINAL WOUNDS

Thoraco-abdominal wounds will require extension of the surgical procedures to repair all of the damage Ines (3) states that the choice of operative approach is subject to the abilities of the surgeon but that it is probably better not to combine the chest and abdominal wounds by cutting across the costal cartilages Many of the injuries of the upper ab- dominal viscera are adequately repaired through the dia phragm in fact some are more easily approached and better exposed in this manner notably injuries of the cardia and posterior wall of the stomach injuries of the splenic flexure of the colon and injuries of the spleen There should be no hesitancy in exploring the entire abdominal cavity by separate incision where there is any doubt or difficulty in handling the intraperitoneal injury through the thoracotomy

Appropriate clinical examination can be performed during the preoperative period Urinalysis is obtained and proctoscopic visualization of the anal canal and lower rectum carried out if there is a possibility of injury to these structures Roentgenographic studies for localization of foreign bodies are useful they do not always give a true estimate of the intraspinal pathology

CHEST INJURIES

Welch and Tuby (7) in a discussion of sucking wounds of the chest observed among battle casualties have suggested the following indications for thoracotomy in such wounds (1) Any large sucking wound with a fracture of one or more ribs (2) Suspected diaphragmatic hernia or perforation of the upper abdomen (3) Suspected continued bleeding from intercostal vessels internal mammary vessels lung liver or mediastinum (4) Presence of large intrathoracic foreign bodies or indriven rib fragments (5) Suspected wounds of the trachea, large bronchi esophagus or heart and (6) Clotted hemothorax

Tuttle (6) *et al* have presented a comparison study of the early definitive and delayed definitive treatment in 320 cases of penetrating and perforating wounds of the chest and conclude that hemothorax is better treated by early aspiration If clotting of the hemothorax occurs and organization takes place decortication of the lung should be resorted to three or four weeks after wounding at which time the fibrin coat is sufficiently firm to allow easy removal Early thoracotomy for clotted hemothorax does not prevent the possibility of a later organizing hemothorax and the incidence of empyema has been slightly higher than in those treated conservatively during the first few weeks Intrapulmonary foreign

are placed on the open vessels The small intestine including its mesenteric border is carefully examined from the ileocecal junction to the ligament of Treitz Perforations are repaired as encountered with a continuous suture of fine catgut and reinforced by interrupted serosal sutures of silk or cotton A transverse closure is preferable and resection is avoided if possible If resection is found necessary clamps should be placed on the open ends and the remainder of the bowel examined to avoid the possibility of having to make a second anastomosis when the two severe lacerations of the bowel could be converted into one without the loss of too large a segment

The colon must be carefully examined, mobilizing the retroperitoneal portions in areas of possible injury Perforations of the colon account for a large percentage of the deaths following abdominal injuries and are better treated by exteriorization, with the possible exception of the smaller wounds that are seen early after injury In the treatment of war wounds of the colon exteriorization was used almost exclusively Mason (4) has outlined the types of colostomies to be used under specific conditions He advised a simple no-spur loop colostomy for (1) Perforations of the antemesenteric portion up to one half the diameter of the segment and (2) The proximal colostomy in perforation of the rectum and lower sigmoid which cannot be exteriorized and must have primary repair or resection He advised a sutured long double-barreled spur colostomy for (1) Perforations of the mesenteric border (2) Perforations of the antemesenteric border larger than one half the diameter of the segment (3) Complete transections and (4) Severely torn or non viable segments requiring resection He emphasized the difficulty encountered with wounds of the cecum and

opening All openings in the diaphragm whether on the left or right should be repaired with a great deal of care to prevent herniae and to lessen the possibility of continued contamination of the pleural cavity from injured abdominal viscera Drainage of all wounds of the liver or pancreas must be through stab wounds in the abdominal wall below the diaphragm

Betts (1) in a discussion on the use of drainage after thoracotomy in these cases states that the objective of complete lung expansion must be pursued vigorously until the end is attained whether or not the chest has been drained Drainage of the chest is accomplished with better results when two tubes are utilized, one posteriorly and the other in the second interspace anteriorly than when one tube alone is used When drainage is not used close observation for the development of fluid in the chest is necessary and aspiration is utilized to achieve the earliest possible complete expansion of the lung

ABDOMINAL INJURIES

It has been repeatedly noted that abdominal signs are not always reliable when there are injuries of the lower thorax The presence or absence of peristalsis is no true criterion of intraperitoneal injury A study of the probable course of the missile and the localization of the retained foreign bodies offers considerable help in arriving at a proper evaluation of the injury

In a systematic exploration of the abdominal cavity bleeding is sought for and controlled Bleeding from the liver can be *temporarily controlled with moist packs bleeding* from large mesenteric vessels can be controlled by digital compression of the root of the mesentery until the clamps

Deformities and contractures of the feet, particularly those incident to the paralysis of the peroneal muscles should be prevented by the early use of moulded footdrop splints

LATE COMPLICATIONS AND SEQUELAE

FRACTURE AND DISLOCATION

Almost all of the spinal cord and cauda equina injuries will have some disturbance of the bony spine but, in most instances of missile wounds it will not result in sufficient destruction to interfere with weight bearing during the period of rehabilitation Many of the closed injuries with compression fractures will present deformities and instability which delay early attempts at ambulation Early reduction

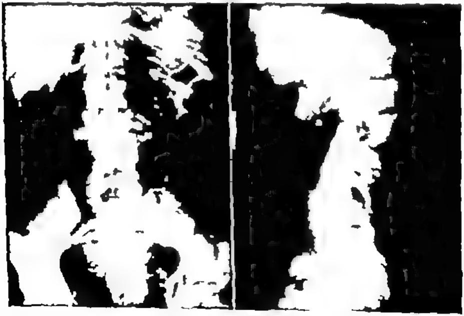

FIG. 1 Case I Extensive destruction of the second lumbar vertebra with dislocation and complete paraplegia.

FIG. 2 Case I Lateral view showing complete anteroposterior dislocation

ascending colon requiring resection and suggested that a long sutured double barreled ileocolostomy designed for early crushing of the spur with a clamp be utilized Perforating wounds of the rectum below the peritoneal floor should have a simple proximal colostomy and drainage of the perirectal space preferably without removal of the coccyx

Wounds of the spleen if bleeding or if extensive, are best treated by removal of that organ Wounds of the liver or pancreas should always be drained through a stab wound in the abdominal wall

During the postoperative course supportive treatment must be continued. It appears that the use of chemotherapeutic agents intrapleurally or intraperitoneally to prevent infection has no advantage over the use of these drugs parenterally Penicillin and the sulfonamides are about equally effective in the prevention of complications Streptomycin because of its wider range of action which includes many of the gram negative organisms may become the drug of preference

SPINAL INJURIES

Debridement of the spinal wounds and exploration of the spinal cord lesion by laminectomy as early after injury as possible will allow maximum opportunity for recovery in partial lesions and will obviate some of the later complications in both the partial and complete lesions of the spinal cord *An attempt should be made to improve* the alignment of the vertebrae in severe dislocations even when the spinal cord lesion is known to be complete This will allow earlier weight bearing during the period of rehabilitation

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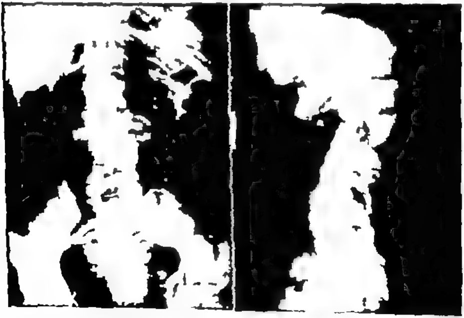

FIG. 1 Case I Extensive destruction of the second lumbar vertebra with dislocation and complete paraplegia.

FIG. 2 Case I Lateral view showing complete anteroposterior dislocation

FIG. 3 Case I Iodized oil injection of the draining wound of the spine showing an abscess cavity above the fourth lumbar vertebra.
FIG 4 Lateral dislocation of the twelfth thoracic on the first lumbar vertebra. Excellent recovery of function after early open reduction.

of severe dislocations will prevent some of the late complications notably local or root pain pressure ulcerations over kyphotic protrusions and instability even when the spinal cord lesion is complete : Extensive wounds with destruction of the bodies of one or more vertebrae and associated infection may defy any satisfactory treatment during the later care of such cases

CASE I · An eighteen year old American soldier incurred an extensive shell fragment wound of the lumbar spine on February 20 1945 resulting in complete paralysis of both lower extremities. The wound was debrided on the day of the injury at a field hospital however several days later the wound developed purulent drainage A large pulsat

ing mass appeared in the right thigh at the site of a small soft tissue wound

On arrival at an Army hospital in the U S A on May 3 1945 he was emaciated and complained of severe pain in both lower extremities There was profuse purulent drainage from the midline wound overlying the second and third lumbar vertebrae There was a large false aneurysm in the right thigh Roentgenograms revealed severely comminuted fractures of the bodies and processes of the second and third lumbar vertebrae with complete posterior dislocation of the upper vertebrae (Figs 1 and 2) Iodized oil injection of the draining sinus revealed an abscess cavity in the region of the third lumbar vertebra (Fig 3)

On June 3 1945 an endoaneurysmorrhaphy was performed for the aneurysm in the right thigh The patient remained acutely ill with episodes of fever and almost constant severe pain in both lower extremities, and required very large amounts of opiates. His condition did not permit any further surgical procedures until January 30 1946 at which time a bilateral cordotomy was performed Following this there was complete relief of the pain in the lower extremities and improvement in his general condition such that he was able to be up in a wheel chair The purulent drainage from the lumbar wound has persisted

The extensive deformity with associated infection present in this patient will prevent the usual degree of rehabilitation that can be accomplished in spinal cord injuries The prolonged confinement to bed incident to the emaciation fever and severe pain has resulted in bilateral multiple renal calculi and pyelonephritis It is doubtful if his condition will ever permit the extensive surgery required to handle the remaining complications

Early laminectomy and open reduction of a severe dislocation is sometimes followed by a considerable return of function in partial spinal cord and cauda equina lesions That this function is jeopardized if reduction is not affected

is true in many instances One patient, on whom open reduction was done shortly after injury had weakness of the left quadriceps muscle as the sole residual of a complete paralysis of both lower extremities (Fig 4) This was especially fortunate since he also had an amputation of the

Fig. 5 Compression fracture of the first lumbar vertebra. Fracture dislocation of the third and fourth lumbar vertebra.

Fig. 6 Case II Osteomyelitis of the fourth and fifth lumbar vertebrae

right arm and would have been unable to use crutches if required Another patient treated with hyperextension for a severe dislocation (Fig 5) and complete paralysis had a footdrop on the left as the only residual Comminuted fractures of the body of a vertebra may produce an irreparable spinal cord lesion by bony fragments protruding into the neural canal This is the usual finding in compression fractures of the vertebrae with paraplegia Early laminectomy

and open reduction is the treatment of choice for all severe dislocations in the partial or complete spinal cord lesions

OSTEOMYELITIS OF THE SPINE

Osteomyelitis of the spine occasionally follows compound fractures of the vertebrae It shows a marked tendency to heal if all loose fragments of bone and all retained foreign bodies are removed and the adjacent soft tissue abscesses are adequately drained Draining sinuses are investigated by the injection of radiopaque oil with fluoroscopic observation and stereoscopic views Surgical exploration along the sinus tract frequently reveals several sequestrated bone fragments Some of these tracts cannot be easily followed to their depths but most can be followed to the vertebral bodies Caution and conservatism are necessary when the sinus tract extends through or near the neural canal especially in partial lesions Paravertebral abscesses are best drained extrapleurally and extraperitoneally by an incision along the lateral border of the spinal muscles Recurrence of an abscess is frequent when healing of the osteomyelitis is delayed Progressive collapse of the vertebral bodies may follow osteomyelitis if adequate support of the spine is not maintained until healing is complete

CASE II A twenty six year old American soldier incurred a shell fragment wound of the lumbar spine on September 14 1944 Celiotomy on the day of the injury revealed a perforation of the ascending colon exteriorization of the colon wound was performed. The lumbar wound was debrided On October 4 1944 a second debridement of the lumbar wound was performed because of continued drainage and a laceration of the dura was found and repaired. Purulent drainage from the wound persisted.

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20 1945 there was purulent drainage from the laminectomy wound overlying the third, fourth and fifth lumbar vertebrae A colostomy opening was present in the right upper quadrant There was a complete paralysis of the right lower extremity and a *partial paralysis of the left lower extremity* Roentgenograms revealed evidence of extensive osteomyelitis of the bodies of the fourth and fifth lumbar vertebrae (Fig. 6) Iodized oil injection revealed that the sinus tract communicated with a large abscess cavity in the right psoas muscle at the level of the fourth and fifth lumbar vertebrae On April 30 1945 the sinus tract was locally explored down to the bodies of the vertebrae and several loose bone fragments removed. The drainage continued and on August 14 1945 the psoas abscess was drained by a paravertebral approach. The laminectomy wound promptly healed and in four weeks all drainage had stopped Six months later a recurrence of the psoas abscess occurred

FISTULAE AND SINUSES

The associated abdominal and thoracic wounds are occasionally followed by persistent fistulae through the spine A fecal fistula through the spine was observed in two patients In one instance, after early laminectomy for an extensive shell fragment wound with destruction of the second lumbar vertebra the wound erupted on the second postoperative day and drained feces and gas The fistula was found to communicate with the ascending colon gradual healing followed ileotransverse colostomy In the second case the fistula persisted much longer and was found to communicate with the sigmoid colon Prompt healing was achieved after a transverse colostomy and local removal of several small sequestrated bone fragments Both of these patients had a stormy course with clinical evidence of meningitis for several weeks after injury

One patient had a fistula through the laminectomy wound which communicated with an opening in the left

ureter This was further complicated by left renal and ureteral calculi left nephrectomy resulted in cure of the urinary fistula

Persistent fecal urinary biliary fistulae which do not communicate through the spine have been observed and appropriate treatment has been required to prevent the constant soiling maceration, and erosion of the skin

Retained shell fragments bits of cloth vaseline packs and rubber drains have been found to be the source of persistent drainage in some of the associated soft tissue wounds

The use of iodized oil has been very helpful in the investigation of draining fistulae and sinuses

EPIDURAL INFECTION

Infection may remain quiescent in the extradural space in apparently well healed spine wounds for some time and later manifest itself by slight elevation of temperature, mild meningismus local pain and root pain at the level of the injury The general condition of these patients fails to improve and they usually have more spasm of the muscles of the lower extremities and more contractures than the uncomplicated cases Tenderness and slight edema over the spine or in the laminectomy wound may be the only local signs of infection Repeated episodes of unexplained fever associated with severe root pain at the level of injury warrants exploration at the site of wounding whether or not laminectomy has been done previously

An occasional case of recurrent meningitis is seen in conjunction with the epidural infection The meninges will usually seal a small opening and meningitis will not result unless there is a foreign body or spicule of bone protruding through the dura and maintaining a communication between

the subarachnoid space and the chronically infected extra dural tissue One patient, seen in civilian life, had three re current attacks of severe meningitis at intervals of several weeks from a small metal fragment lodged in the cervical spine and protruding through the dura. Spinal cord injury was not present No further attacks of meningitis occurred after removal of the foreign body

When a spicule of bone is maintaining the opening through the dura, it will usually not show on the roent genogram and may be difficult to demonstrate at operation.

CASE III A twenty-eight year old American soldier in curred a shell fragment wound of the lumbar spine with partial paralysis of both lower extremities on November 19 1944 Laminectomy on the day of injury revealed a small shell frag ment in the epidural space and a laceration of the third lumbar nerve root on the left Postoperatively there was leakage of spinal fluid from the wound of entrance five centimeters to the left of the spine On December 16 1944 the spinal fluid drainage stopped the following day the patient became acutely ill with temperature of 104 F., rapid pulse and stiff neck. A spinal puncture was not done at that time He continued to have intermittent fever associated with severe headaches and burning pain in both lower extremities.

On arrival at an Army hospital in the U S A. on January 17 1945 the patient presented an extreme degree of emacia tion There was a well healed wound just to the left of the third lumbar spine and a well healed laminectomy wound which extended from the first to the third lumbar spines. There were weak contractions of both quadriceps muscles as the only evidence of voluntary motor function in the lower extremities. On January 29 1945 an intravenous pyelogram revealed a slight hydronephrosis on the right the left kidney was enlarged and excreted no dye It was thought that the persistent fever and extreme emaciation were due to this On January 31 1945 the left kidney was removed and found to contain thick purulent material and cortical abscesses Postoperatively the patient felt much better and appeared improved Ten days later he

developed a sudden severe headache followed by a rise of temperature to 103 F On the following day he continued to have elevated temperature associated with headache and slight stiffness of the neck. A spinal puncture revealed a white cell count of 4 400 with 99 percent polymorphonuclear leucocytes. Culture of the fluid was negative. Two days later the spinal fluid cell count was 800 and the culture revealed *Bacillus pyocyaneus* The patient s condition gradually improved although intermittent headaches and moderate elevations of temperature continued On March 15 1945 the patient developed a temperature of 104 F; pulse 160 became irrational and appeared critically ill. The spinal fluid cell count was 2 000 The following morning the patient s temperature was 99 F he was rational and appeared improved On March 26 1945 he had a similar episode of headache, fever and stiffness of the neck. He had gained no weight since admission. His estimated weight was 90 pounds

On April 26, 1945 a small incision was made through the laminectomy wound under local anethesia. The epidural fat was edematous but an abscess cavity was not found A small rubber drain was left in the epidural space and the end brought out through the incision which was loosely closed. The previously used chemotherapy was continued The patient made a remarkable recovery and had no further evidence of intraspinal infection During the next five months he gained 50 pounds in weight and showed progressive return of motor function in the lower extremities He was able to walk with the use of crutches and light footdrop braces by January 1946

Because of the patient s precarious condition at the time of operation only limited exposure of the extradural space was possible Leakage of spinal fluid was noted when the third lumbar nerve root was dissected free in the region of the intervertebral foramen a definite spicule of bone protruding through the dura was not demonstrated The subsequent course, however indicated that the epidural focus of infection and its communication with the subarachnoid space was disrupted by the operative procedure

OSTEOPOROSIS AND PARA ARTICULAR CALCIFICATION

There is rapid decalcification of the bones of the lower extremities incident to the paralysis and immobilization This osteoporosis may be extreme when confinement to bed is prolonged but usually will gradually regress as activity is increased Fractures may occur in the osteoporotic bone and may not be recognized promptly because of the lack of pain There is crumbling of the soft bone at the site of fracture which may produce deformities sufficiently marked to prevent further rehabilitation

One patient was observed who sustained a fracture of

FIG 7 Late fracture of the neck of the femur in a paraplegic patient showing crumbling and para-articular calcification

FIG 8 Extensive para articular calcification about the knee joint in a patient with paraplegia of four and one half months duration

the neck of the femur while turning himself in bed This was not recognized for several weeks and has resulted in a deformity (Fig 7) which makes it difficult for him to sit in a wheel chair and impossible to begin ambulation with the use of braces These fractures resemble the Charcot s neurotrophic point in many respects

In patients with severe mass reflexes fractures of the articulating surfaces of the hip and knee joints may result from the sudden and forceful muscular contractions

Para articular calcification occurs about the hip knee and ankle joints in many of the parplegic patients It is usually mild and of no great consequence but in an occa sional patient it may so limit motion of the joints that full rehabilitation is not possible Marked limitation of knee flexion makes sitting up difficult unless leg supports are provided (Fig 8) Many theories have been presented to ex plain the development of this calcification Derra and Nader mann (2) suggest that nerve impulses from irritative lesions in the spinal cord may be responsible Nachlas and Olpp (5) in discussing para articular calcifications (Pellegrini Stieda) in affections of the knee believe that it begins as degenerative changes in the connective tissue about the knee and is followed by small localized encapsulated hemor rhages which under proper physical and chemical conditions become calcified There are several factors which appear to influence the development of para articular and soft tissue calcification in the paraplegic patients There is excessive resorption and excretion of calcium during the period of immobilization Some of the patients have prolonged edema of the lower extremities beginning shortly after the in jury This results in stagnation of body fluids and fixation of organic phosphorus compounds in the connective tissue about

the joints which under the influence of paralysis and increased calcium mobilization become calcified Surgical treatment *is not indicated*

COLOSTOMIES

Many of the patients with war wounds of the spine have a colostomy which was done for an associated injury to the colon, and express the desire to have it closed as soon as possible Although the colostomy has served its primary purpose after a period of a few months there appears to be some advantage in not closing a properly placed and well functioning colostomy especially if the spinal cord lesion is complete

In an attempt to attain self sufficiency one of the most difficult adjustments for the paraplegic patients is the regulation of bowel evacuation Some of the patients develop a reflex bowel routine but many remain incontinent and must constantly wear pads others will require frequent enemata or laxatives Adequate personal care and cleanliness is almost impossible for the patient to maintain without the aid of an attendant A colostomy in the transverse, descending or sigmoid colon can be very well managed by the patient and will solve one of the major problems that he encounters when he returns home It has also been noted in paraplegic patients that those with a colostomy usually have fewer decubitus ulcers than those without a colostomy When ulcerations are present, they tend to heal faster in patients with a well functioning colostomy probably due to less maceration and contamination in the region of the ulcerations

Colostomies proximal to the transverse colon should be closed because of the frequent soiling and the skin irri

tation incident to the soft or liquid feces Colostomies below the level of the transverse colon offer many advantages and these should be carefully considered before closure is contemplated Patients who have had a colostomy since the time of the original injury find it difficult to appreciate the advantages it may offer The few patients who have had an elective colostomy for other reasons late after the spinal cord injury have been impressed with these advantages and they prefer not to have closure of the colostomy None of the patients observed has had a colostomy for convenience alone although it may prove to be a worthwhile procedure for certain selected individuals in whom it would not be an additional mental hazard

UPPER EXTREMITY INJURIES

Fractures of the long bones in the upper extremities that have been observed in the paraplegic patients have seldom interfered with attaining a satisfactory degree of rehabilitation. Fractures about the elbow joint resulting in ankylosis may require special adjustments of the walker or crutches but usually allow adequate use of the extremity unless the angle of fusion is less than 90 degrees. Particular attention must be given to prevent stiffness of the elbow wrist and fingers following injuries of the upper extremities in which immobilization has been used so that ambulation can be started as soon as possible

Injury of the brachial plexus or of two or more of the major nerves of an upper extremity, will render that extremity useless for the handling of crutches until some recovery of nerve function has occurred A single isolated nerve injury of an upper extremity even if irreparable is compatible with crutch ambulation Tendon transplants may

be required in some of the patients Hemiplegia resulting from a concomitant cerebral wound may render an upper extremity useless A spinal cord injury at the level of the seventh cervical segment or above results in marked disability of both upper extremities these patients cannot bathe, feed, or dress themselves They do not have sufficient function in the upper extremities to permit ambulation with braces and crutches

Severe injuries of an upper extremity necessitating amputation will prevent a satisfactory rehabilitation in all of the complete lesions of the spinal cord and in many of the partial lesions of the spinal cord and cauda equina

MISCELLANEOUS

Aneurysms of the carotid subclavian axillary and femoral vessels have been observed among the paraplegic patients the surgical treatment of these defects has not interfered with satisfactory rehabilitation

Phlebothrombosis and thrombophlebitis, although infrequent in these patients has been observed and pulmonary infarcts have occurred Such cases have little or no pain and associated vasospasm Unilateral edema may be marked during the acute phase of a thrombophlebitis but persistent disabling edema is unusual The infrequency of these complications is probably related to the widespread vascular relaxation in the lower extremities that occurs when a spinal cord lesion exists at or above the first lumbar segment.

Severe contractures of the tendon Achilles resulting from an unsupported footdrop may require tenotomy or tendon lengthening Fusion of the ankle or subastragalar joints to prevent further foot deformities is seldom justified, since crumbling of the osteoporotic bone and neurotrophic changes

similar to those seen in Charcot s joint may be initiated The generalized spastic contractures of the lower extremities are discussed elsewhere in this monograph

Severe injuries to the lower extremities that have required amputation will interfere little or none with rehabilitation in the complete spinal cord lesions The braces for such cases will need a suitable extension with a shoe attached on the side of the amputation Bilateral amputation of the lower extremities was not present in any of the paraplegic patients studied There are no available reports of bilateral amputation that have been done to lower the center of gravity or remove functionally useless weight the consensus at present is that such a procedure is not justified

The patient and attendants should be advised to examine the feet periodically The skin is usually dry and prone to peel and crack unless oil is applied. Infected ingrowing toenails are very frequent in the paraplegic patient and are often neglected Many can be managed with proper paring of the nails others will require excision of the lateral borders of the nail including the corresponding portion of the nail matrix to prevent troublesome recurrence

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Chapter VI

TREATMENT OF DECUBITUS ULCERS

DONALD EARL BARKER, M.D

INTRODUCTION

Prior to World War II the treatment of decubitus ulcers was considered a medical problem and surgery was rarely employed During the recent war Army general hospitals in the United States confronted with a large number of patients with decubitus ulcers following spinal cord injury sought an improved form of treatment Trials with surgical reconstruction of the ulcers produced remarkable results and have now led to a new concept in regard to definitive treatment The surgical principles laid down here are based on observations in more than two hundred and fifty paraplegic patients treated during a period of eighteen months

INCIDENCE AND PATHOGENESIS

In the series of patients personally observed 47 per cent had one ulcer, 23 per cent had two ulcers 19 per cent had three ulcers and 4 7 per cent had five or more ulcers The decubitus ulcers ranged in size from areas one by one and a half inches to larger ones six by eight inches Location of the ulcers in order of their frequency was found to be as follows over the sacrum, trochanter heel iliac crest, ischial tuberosity and tibial prominence

Constant pressure on the skin over one of the areas just mentioned for a period of more than four hours causes signs of ischemia.

The earliest clinical sign of trouble is a slightly reddened area over a bony prominence which blanches on pressure and is slightly warmer than the surrounding skin. Good nursing care is imperative to avoid further adverse change Gentle massage of the suspicious area twice a day the benefit of carefully applied radiant heat, and avoidance of additional pressure may prevent further changes in the skin and permit the circulation to return to normal within a week

If deterioration of the skin continues irreparable damage has been done The central part of the area of hyperemia becomes black and eventually sloughs

TREATMENT

Good general condition of the patient is imperative for success in the treatment of the ulcer This is facilitated by a high caloric diet multi vitamins and transfusions of whole blood if the red blood cell count is below 4 200 000 per cu mm. Nutritional problems of the paraplegic patient are considered in detail in another chapter of this book.

Marked protein loss occurs from decubitus ulcers after slough separates The loss can be measured by collecting the debris and secretions for 24 hours on a nitrogen free cellulose pad and determining the nitrogen content by the Kjeldahl method Daily loss of 5 5 to 50 0 Gm of protein is common When the loss is large transfusions of plasma are required to maintain or improve the level of blood proteins and ensure the proper albumin globulin ratio

Local dressings will be needed prior to surgical treatment

of the ulcer. Because of the maceration of the skin caused by wet dressings we prefer an ointment type of application Codliver oil ointment on sterile gauze, renewed daily inhibits the accumulation of a purulent discharge and perhaps aids the healing process. Necrotic tissue usually evident in an ulcer after 14 days should be removed by sharp scissor dissection

The optimum time for surgical treatment is dependent on the general condition of the patient as well as the appearance of the ulcer As previously mentioned a good nutritional state is imperative A splendid appetite and bright appearance, in addition to normal laboratory data suggest a satisfactory general state The ulcer should be covered with a bright red layer of granulation tissue prior to operation Multiple areas of slough pockets of pus or pale granulations are contraindications to surgery

TYPES OF OPERATIONS

Several types of surgical procedures are at our disposal for the treatment of decubitus ulcers Small ulcers over the sacrum or back can be improved by excision and direct closure Large or multiple ulcers over the back or sacrum can be treated by skin grafts or by advancement of skin flaps An ulcer over the trochanter can be handled best by a skin flap from an adjacent area Direct closure or skin grafts over the hip have not been permanently successful because of the rotary motion of the trochanter as the patient changes position To prevent the dissecting action of the greater trochanter during the immediate postoperative stage both legs can be bandaged together the opposite leg acting as a splint for the leg that has just been operated on.

OPERATIVE TECHNICS

EXCISION AND DIRECT CLOSURE

In small ulcers over the back the surrounding tissue is undermined sufficiently so that the skin edges can be brought together without tension A stab wound is made in the periphery of the undermined area, and a small rubber dam drain is inserted The edges are then closed with 00 chromic catgut for the deep tissues and multiple interrupted sutures of C silk for the skin edges A dressing of xeroform gauze and mechanics waste is then applied Figures 1 2 and 3 show the preoperative and postoperative appearance of a small ulcer treated in this manner

During the first three days following operation no change of dressing is indicated By the third day there will be a large amount of serous drainage from the area, and the dressing will have been completely soaked The suture line is cleansed with hydrogen peroxide to remove the serum and is then dried with ether Powdered sulfanilamide is dusted along the suture line and a dry dressing is applied Hereafter the dressings are changed daily up to about the twelfth day The drain is partially removed on the fifth day and is completely removed on the sixth day Drainage from the stab wound usually ceases by the eighth to the tenth day

SKIN GRAFT

In the large ulcers of the back two methods of operation can be used In the debilitated patient the application of a split thickness skin graft about $^{14}/_{1000}$ of an inch in thickness is the method of choice At the time of operation the granulation tissue is shaved down to a good bleeding base and then the bleeding is controlled with hot packs and occasion

FIG. 1 Small ulcer of back—preoperative.

FIG. 2 Small ulcer six weeks after operation—direct closure

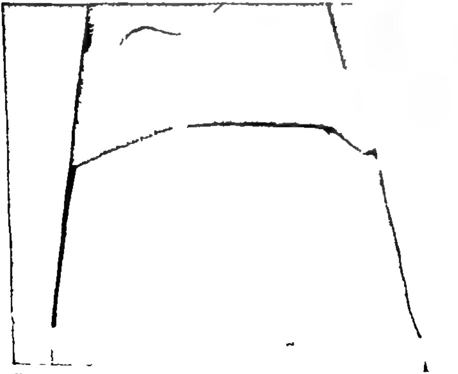

FIG. 3 Small ulcer fourteen months after operation—direct closure

FIG 4. Large sacral ulcer

FIG. 5 Large sacral ulcer two months after skin grafting

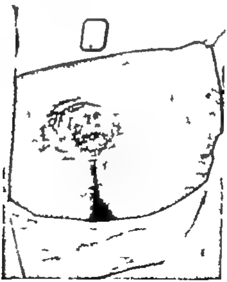

FIG 6 Large sacral ulcer six months after skin graft (From Barker Elkins and Poer *Ann Surg* 123 523 1946)

ally the use of adrenalin The skin graft is then laid on the granulation and sutured into place with a continuous stitch of 000 silk Multiple small stab wounds are made in the graft to give adequate drainage and a pressure dressing of xeroform gauze and mechanics waste is then applied

In no case has there been any difficulty in healing of the donor site Most are healed by the tenth postoperative day

Figures 4 5 and 6 show preoperative and postoperative appearance of a large ulcer treated in this manner

After operation the dressing is carefully removed on the third day, and the graft is cleansed with hydrogen peroxide and ether It has been found that a dry dressing with sulfanilamide powder sprinkled over the top changed daily produces the best results Early in our experience wet dressings were used, but discontinued because of the maceration of the graft itself In a number of cases scarlet red ointment was used during the entire period of dressing Dressings are continued daily until the area is entirely healed

Observation over a period of one year and a half shows that some of the grafts will break down because of trauma during exercise In these cases it has been the policy to reoperate at a later date excise the graft completely and bring normal tissue to the area by the advancement of skin flaps Fortunately in these cases the bleeding is very much less than in a primary closure and the operation can be done with very little blood loss even though the graft area is of considerable size

ADVANCEMENT OF SKIN FLAPS

Another type of operation is indicated in the patient who is in good clinical condition Extensive undermining

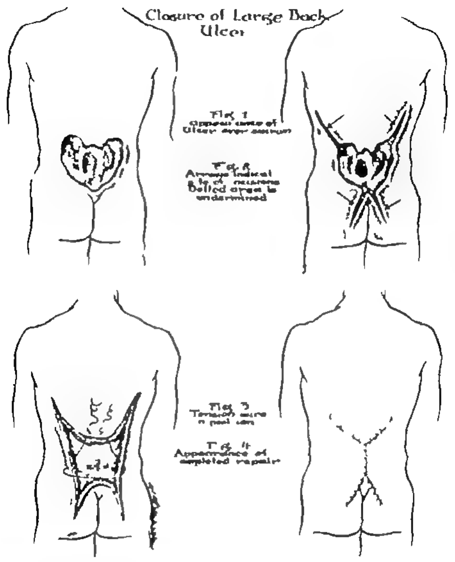

FIG 7 Diagram of closure of large sacral ulcer by advancement of skin flaps

(1) Appearance of ulcer over sacrum.

(2) Arrows indicate site of incisions Dotted area is under minded.

(3) Tension wire in position

(4) Appearance of completed repair

of the surrounding tissue and the use of advancement flaps are indicated as shown in Figure 7

Because excision of the granulation tissue over a large area produces marked bleeding and many perforating branches of arteries are cut through a fairly large blood loss is almost certain It is recommended that these patients be typed before operation and a blood transfusion given during the operation After the area has been undermined completely so that the skin edges can be brought together without tension they are approximated deep tissues closed with 00 chromic catgut and superficial tissue with multiple sutures of C silk Stab wounds are made in any dependent portion of the undermined area and rubber drains are in serted Xeroform gauze is then applied over the skin edges and a pressure dressing of mechanics waste is used Figures 8 9 and 10 show the preoperative and postoperative appear ance of a large ulcer treated in this manner

In the large advancement type of operation the dressings are essentially the same as those in the small closure with the exception that the pressure dressings should be continued up to about the 15th day Otherwise in a small percentage of cases there is a serous collection underneath the upper flap

ROTATION SKIN FLAP IN TROCHANTERIC AREA

In ulcers over the hip it is advisable to use some type of flap from the adjacent area to cover the defect as shown in Figure 11

At the time of the operation the ulcer area and granula tion tissue are excised completely and a pattern made of the defect which is used to form the flap Ventrally acquired flesh is preferable because the skin on the ventral portion

FIG. 8 Large sacral ulcer—preoperative

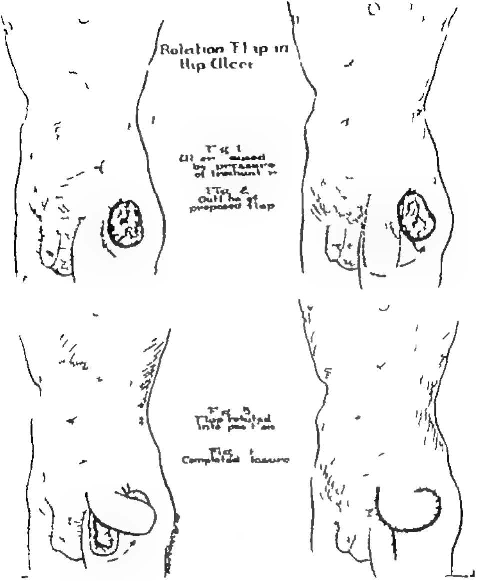

FIG. 11 Diagram of rotation skin flap for ulcer over trochanter

(1) Ulcer caused by pressure over trochanter
(2) Outline of proposed flap
(3) Flap rotated into position.
(4) Closure completed.

←
FIG. 9 Large sacral ulcer three weeks after operation by advancement of skin flaps

FIG. 10 Sacral ulcer (as in Figs 8 and 9) two months later

FIG. 14 Hip ulcer (as in Figs 12 and 13) six months later

of the thigh is much freer than that over the buttock area

A stab wound is made in the lower part of the undermined area so that complete drainage will be accomplished when the patient is lying on his back A large pressure dressing of xeroform gauze and mechanics waste is then applied Due to the fact that the patients have little if any sensation a large amount of adhesive tape is applied in the initial dressing to compensate for the loss of protective reflexes The opposite leg is used as a splint for the operative side

Following operation the area is dressed on the third day the suture line is cleansed and powdered as above Care

←

FIG 12 Hip ulcer (trochanteric) preoperative

FIG 13 Hip ulcer two weeks following rotation skin graft.

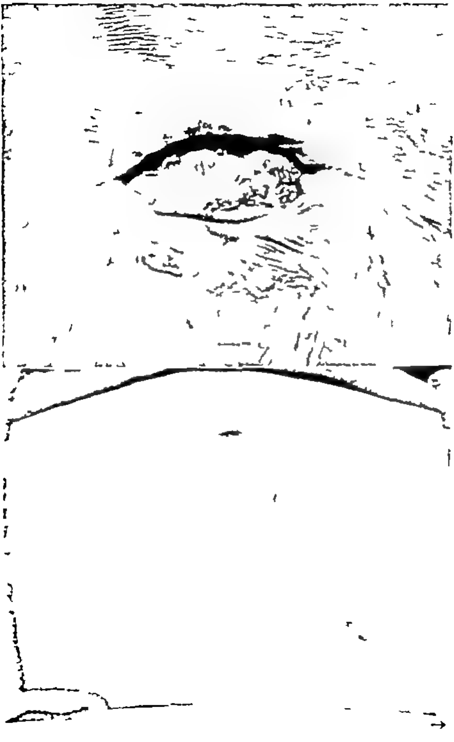

FIG 14 Hip ulcer (as in Figs 12 and 13) six months later

of the thigh is much freer than that over the buttock area

A stab wound is made in the lower part of the under mined area so that complete drainage will be accomplished when the patient is lying on his back A large pressure dressing of xeroform gauze and mechanics waste is then applied Due to the fact that the patients have little if any sensation a large amount of adhesive tape is applied in the initial dressing to compensate for the loss of protective reflexes The opposite leg is used as a splint for the opera tive side

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FIG. 12 Hip ulcer (trochanteric) preoperative.

FIG. 13 Hip ulcer two weeks following rotation skin graft

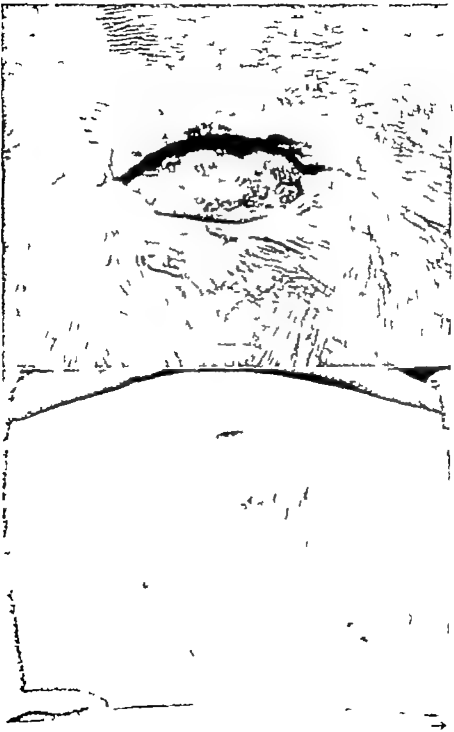

FIG 17 (*above*) Early break down of ulcer shown in Fig ures 15 and 16

FIG. 18 Same ulcer (Figs 15 17) twelve months later (From Barker *Am J Surg* 74 180 1947)

should be used in each dressing to produce as much relaxation in the suture line as is possible Usually the legs are kept bandaged together until the sutures are removed on the twelfth day Figures 12, 13 and 14 show the preoperative and postoperative appearance of an ulcer treated in this way

It is recognized that the use of full thickness skin with fat padding is superior to skin grafting when this can be accomplished. However there are a number of cases in which the clinical condition is so poor that they cannot stand extensive surgery or blood loss It is in this type of case that the skin grafting which can be done in one hour i time with very little blood loss and shock, is the method of choice When the patient improves removal of this graft and replacement by full thickness skin and fat is indicated Over a period of a year s observation sixty per cent of the grafts have tended to break down Figures 15 to 18 inclusive illustrate the remarks in this final paragraph

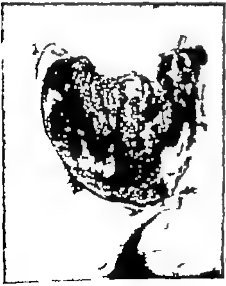

FIG. 15 Huge ulcer—preoperative
FIG. 16 Huge ulcer covered by skin graft.

FIG. 1 Balkan Frame attached to hospital bed with trapeze bar May be easily duplicated domestically Note padded block at foot of bed to prevent plantar flexion of feet A firm mattress or fracture board under the mattress should be employed A pillow should be placed lengthwise under the calf muscles, extending to the popliteal space so that the heels are clear of the mattress in the supine position In the prone position, pillows should be placed under the tibial crests to prevent the toes from coming in contact with the mattress and to encourage the position of normal dorsiflexion of feet

bar and foot-drop board (Fig 1) A Stryker frame may be necessary temporarily for a patient with severe sacral decubiti (Fig 2) These devices permit the patient to begin *helping himself* early in his convalescence It is at this point that the patient must be imbued with the goal he must attain — that of *independence from others* and *self reliance* The patient as soon as it is possible, without other contraindications due to healing of fractured vertebrae, operative in

Chapter VII

THE GENERAL REHABILITATION PROGRAM

WILLIAM G KUHN JR M.D

INTRODUCTION

Immediately upon the establishment of the diagnosis of an injury to the spinal cord, steps should be taken to rehabilitate the patient It is a proved fact, the patient being willing that in any lesion below the cervical level of the spinal cord, rehabilitation to a degree of independence and self reliance *can* be accomplished

For purposes of discussion the rehabilitation of a paraplegic may be divided into two phases The Bedridden phase and the Ambulatory phase In practice there is no gap between the two phases Rather an imperceptible transition from one to the other takes place

I BEDRIDDEN PHASE

In planning such a program it is necessary to procure a few essential pieces of equipment These may be purchased from commercial sources or in some instances manufactured by members of the patient s family

The apparatus that is most easily reproduced domestically and is most essential to instituting a regime of rehabilitation for the patient is a Balkan frame with trapeze

Fig 4b Alternate method of getting from wheelchair into bed Patient lifts himself using trapeze bar and arm of chair to sit on edge of bed He then shifts arm from wheelchair to mattress and pulls himself back onto the bed. Legs follow This method is used where patient has limitation in flexion at the hips It is likely to bruise the sacrum, trochanters and legs

FIG. 4a. Getting into bed from wheelchair (method of choice) Legs are placed in bed first Grasping trapeze bar and arm of chair patient raises himself and swings into bed This is the method of choice because patient is less likely to bruise sacrum trochanters or legs (Note rubber air ring on seat of chair)

FIG. 5 Patient using one method of moving from floor to wheel chair by performing hand stands on wheels of chair Patient has moved from floor to footrest and then from footrest to seat of wheel chair (Note use of crutch to chock wheels by its insertion through the spokes)

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FIG 6a. First position taken in getting into bathtub Patient sits on edge of chair with feet hanging over edge of tub Chair should be held tightly against tub by chocks placed under the wheels A bed room slipper is satisfactory

FIG. 6b Second position taken in getting into bathtub Patient bal ances himself on edge of tub (if there is no handle on soap dish, the far side of tub is used) Knees should be extended as far as possible so that as patient lowers himself his legs will not double under him. Getting out of tub is the reverse of getting in


A
B

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FIG. 7 Procedure for getting from wheelchair into common chair Wheelchair should be placed at edge of common chair at angle of about 60° to 80° Patient sits on edge of wheelchair and reaches across either to the seat of the chair or better to the far armrest Knees should be at least partially extended to act as pivots. If patient's arms are weak, the brace nearest the chair should be locked for full use as a pivot. In getting from common chair to wheel chair the procedure is reversed.

He is also to be impressed with the rule that, consequently more will be required of him, and that less help from attendants will be forthcoming

Various methods of entering and leaving a wheelchair (Fig 4) should be demonstrated and then the patient required to perform the maneuvers himself from that time on. Periods of time spent in the wheelchair may be gradually increased but should be carefully followed by inspection for developing decubiti Use of foam rubber pads pillows, or rubber air rings on the seat of the chair are essential to prevent damage to the anesthetic skin.

Having assumed a wheel-chair existence the patient does not discontinue his efforts towards obtaining extremely powerful muscles of his upper extremities Rather he intensifies his efforts not only by continued use of the trapeze bar and weights in bed, but also by frequently performing hand stands while in the wheelchairs At this stage the patient can be given bar bell and weight lifting exercises that he can perform from the floor or on a gymnasium mat in the supine position The patient can also at this time begin to learn the various methods and maneuvers for moving from wheelchair to floor and back to wheelchair (Fig 5) entering and leaving a bathtub from wheelchair to get on and off a commode from a wheelchair to get in and out of common chairs and in and out of a car from a wheelchair (see Figs 6 7 8)

PHYSICAL THERAPY

Physical therapy is inserted at this point to give added emphasis to the dictum that should be established with this type of patient that physical therapy rightly begins from the very day of injury and extends throughout the bed ridden

phase and the ambulatory phase It is felt by Kuhn (1) to be as important to the rehabilitation of the patient as is the care of the bladder, decubiti and maintenance of nutrition It is often the physical therapist who actually detects the first sign of returning function in these patients In the daily application of active (not passive) re-education exercises for the lower extremities in the unproved anatomically complete lesions it is the physical therapist who has the best opportunity to observe minute changes in motor function Passive exercises should include movements that take the paralyzed extremities through all ranges of motion at the hip knee and ankle joints Failure to observe this practice daily in the bed ridden stage will result in deforming and troublesome contractures due to fibrotic changes in the muscles

Active re-educational exercise is greatly emphasized because it is felt that in many muscles or muscle groups what at first appears to be paralysis is due to extreme weakness or as is frequently the case to the fact that the patient has forgotten how to use these groups since the extremity as a whole does not function (e g quadratus lumborum, preserved usually in lesions below D 10 vertebral level) Through repetition and constant training the patient may be taught not only to strengthen any single muscle or muscle group not permanently paralyzed but also to learn how to substitute the unaffected muscles Even in the presence of spasticity a patient can be taught to relax and contract on command If this can be accomplished we consider the patient to have voluntary contraction of the muscles involved By constant practice the patient can lengthen the period during which he has voluntary control of the spastic muscles

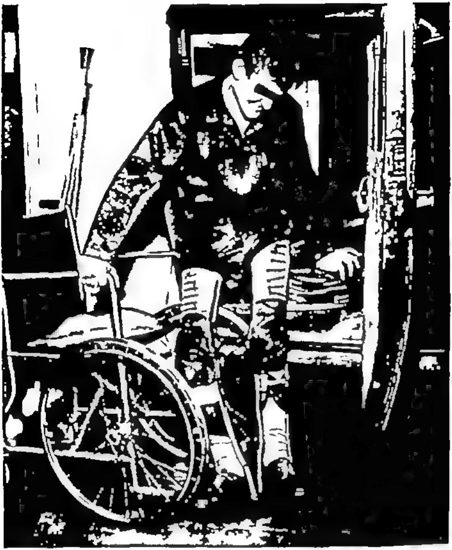

FIG 8 (Courtesy of Journal of Neurosurgery) Procedure for getting into automobile from wheelchair Patient locks knee of brace nearest to car (Other brace may be locked but is not necessary) One hand is placed on seat, the other on arm of wheelchair (Chair must be steadied either by crutches through spokes of wheels, or by rotating rear wheels of wheelchair at right angles to front wheels, or by parking chair against body of automobile) Using locked brace as a pivot, patient swings up and around to lean against seat of car Right hand may then be moved from wheelchair to door jam as patient pulls himself backwards onto seat of car Getting out of car is the reverse of getting in

tion for new developments in braces has been opened up

In practically all cases the paraplegic does not have a deformity of the skeletal make up of his lower extremities His difficulties lie within the realm of the neuro-muscular system The braces need not be of weight bearing design In effect, the prosthesis for a paraplegic must be designed to splint the leg so that the knee becomes immobilized in order that the weight be transmitted through the knee joint in a normal manner In addition a stop of some sort is necessary to prevent his foot drop from interfering with ambulation.

The ambulatory paraplegic who must literally manipulate the "dead weight of his lower extremities by action of his quadratus lumborum abdominus recti or shoulder girdle muscles finds braces of primary importance The braces must be as light as possible without loss of strength and durability

We have followed the precept of using long walking calipers without a pelvic band in those cases with preserved quadratus lumborum muscles The pelvic band has not been found to add appreciably to hip stability and, in addition it prevents the unhampered action of the quadratus lumborum muscle in ambulation. If hip stability becomes a problem a sacro-abdominal belt is used Girdles of the two-way stretch type have proved satisfactory If the function of the quadratus lumborum has been lost, pelvic bands or thoracic cages (Figs 9b 10b) are necessary even though they add to the total weight of the appliance.

The walking caliper in use at present is not considered to be the perfect brace Much remains to be accomplished One type caliper in use (Fig 9a) is made of a combination of light weight tool steel of high quality and duraluminum with a drop-lock at the knee and a drop-foot spring or per

This re-educational training aids greatly in teaching the patient various gaits on crutches

During the bedridden stage, physical therapy treatment consists mainly of three phases First, daily radiant heat of 20 to 30 minutes duration is applied to the affected extremities Second massage is given to those patients with edema, contractures and vascular disturbances It has not been given in cases of spasticity unless the spastic condition is accompanied by the above mentioned conditions The third phase of this treatment during the period of confinement is re-educational exercises which are given daily for thirty minute periods Complete muscle evaluation tests are done every one or two months and recorded for future comparison and study

Physical therapy and reconditioning go hand in hand and must be constantly applied by both patient and instructor until the patient has become ambulatory to such a degree that he may be relied upon to perform his exercises himself

II AMBULATORY PHASE

BRACES

In the past decade there has been a marked scarcity in available reference literature on the subject of braces and orthopedic appliances for paraplegics This is due partially to two factors First until World War II there was no urgent need for such literature The incidence of spinal cord injuries in civil life was relatively low as compared to a like period in war time Secondly modern metallurgical research has in the past decade produced metal alloys which are of lighter but of equally strong composition as steel It is the opinion of the writer that a field for active investiga

tion for new developments in braces has been opened up

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FIG. 92. Group of long-leg walking calipers of various metal construction. Left to right (1) tool steel, (2) duraluminum, and (3) steel, ball bearing knee joint (from artificial limb) with riveted duraluminum shanks.

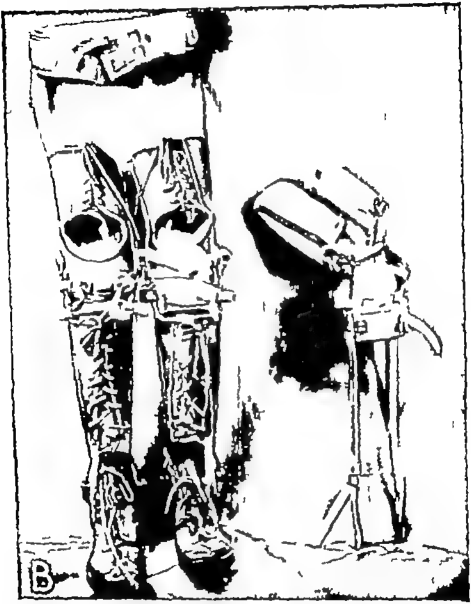

Fig 9b Brace comparison (Courtesy of Journal of Neurosurgery) Brace on right is the caliper type has no pelvic band With its mate and with shoes attached, it weighs 7 pounds 2 ounces Caliper brace on right has duraluminum shanks and steel ball bearing knee joint from an artificial limb

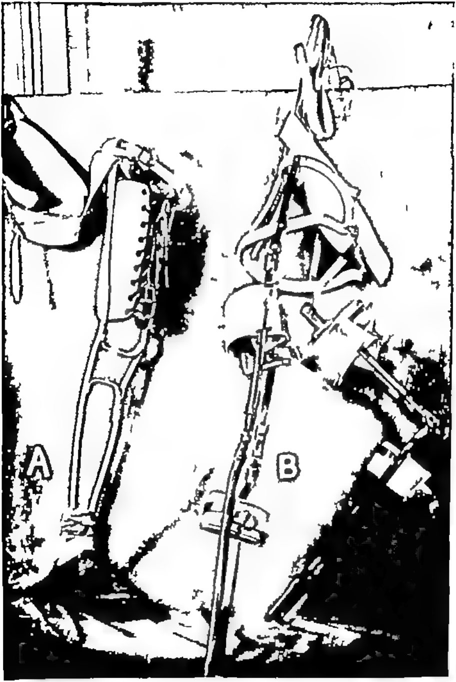

FIG 10a Brace designed for an above knee amputee paraplegic with a complete spinal cord lesion at T 10 Brace has leather pelvic
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manent stop if desired The upper part of the caliper including the drop-lock joint is made from the steel knee brace on the prosthesis used for below knee amputation The joint, therefore is a ball-bearing joint of great strength and ease of motion The lock is a fitted ring which drops down to fix the joint when in extension The lower part of the caliper from approximately four inches below the knee to the caliper pivots at the heel is made of duraluminum which is riveted to the steel knee joint (*duraluminum cannot be welded*) This helps decrease the weight markedly without decreasing the strength of the brace The brace is held in place by a leather cuff at the thigh and calf of the leg Both cuffs are re enforced with duraluminum bands posteriorly If needed a strap is riveted onto the brace at the ankle to hold the calipers firmly in the shoe

The weight of this brace without shoe is two pounds and nine ounces Each shoe weighs one pound A pair of braces with shoes attached would then weigh seven pounds and two ounces Thus a walking caliper of great strength durability ease of motion through the ball-bearing joint and of light weight was devised using readily accessible material and employing a minimum amount of labor for construction

The drop foot brace used in lesions of the cauda equina is of light weight 14 gauge steel wire with a posterior leather cuff strengthened by a duraluminum band at the calf (Fig

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band, ischial weightbearing ring leather thigh cuff and artificial foot. Drop lock at knee joint was incorporated later

FIG 10b Thoracic cage and calipers designed for a patient with a complete lesion at T 3 Total weight without shoes, 9 pounds 3 ounces Drop locks at knees operated through remote control at hips by rudder cable from an air plane

FIG. 11 Drop foot brace showing attachment to shoe by loops of the wire around pinion through heel of shoe. Brace is detachable and weighs about 9 ounces without shoe Cuff is made of leather re-enforced by duraluminum posterior band

11) This brace is fastened to the shoe on a pinion through the heel and is detachable from the shoe Each brace weighs nine ounces without the shoe

The advantages of the walking caliper and drop foot brace which are detachable from the shoe are mainly economical This type allows for interchange of shoes with little or no expense. In addition it is easier for a patient to put on

and remove calipers if the shoe and brace can be applied independently of each other

SPECIAL DEVICES

Figure 12 illustrates a device for correction of drop foot by tendon stretching devised by R N Hatt M D (2) It is comprised of a plaster of Paris shoe across the sole of

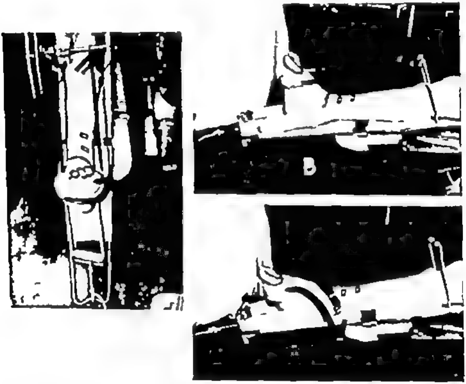

FIG. 12a. (Courtesy of Journal of Neurosurgery) Anterior view of tendon stretcher with tubing in place Buck's extension Thomas splint and incorporation of tubing in plaster shoe is demonstrated

FIG 12b Lateral view of tendon stretcher with rubber tubing hooked in place.

FIG. 12c Lateral view of tendon stretcher without rubber tubing being hooked in place Marked foot drop thereby demonstrated.

which is incorporated a length of rubber tubing similar to that used in suction hoses in the operating room The ends of the tubing are fastened to an upright by means of hooks This upright and lower extremity are supported on a Thomas half ring splint by a stocking sling Buck s extension of moleskin with a spreader is applied to the leg and is fastened to the distal end of the Thomas splint in order to give counter traction If the rubber hosing is attached to the upright with the hooks and tension adjusted to bring the foot into neutral position by moving the upright forward or backward the Achilles tendon can be lengthened gradually Usually 10 to 14 days of constant traction will suffice to lengthen the tendon The supporting apparatus may be removed during the night. The plaster of Paris shoe and the patient s foot are checked daily for proper fitting edema or for the development of blisters or decubiti

AMBULATION

The gait which a patient will use in walking depends largely on two factors First it depends upon the level of his lesion If the patient has preservation of the quadratus lumborum muscles he may be successfully taught the Step-Through (4 point gait) or he may learn the Swing To (3 point gait) and Swing Through gaits In the event that his lesion is well above the level of the 10th dorsal spinal segment he will have no choice in the matter since he will have to use the Swing To gait The second factor in choosing a gait is purely a psychological one The majority of patients in wartime experience were all young men between the ages of 18 and 30 years of age A few were between 30 and 45 years of age All these patients were started in their rehabilitation within two or three months

after their injury It has been our experience that those patients who are rehabilitated early after their injury show a decided preference for the Step-Through gait They express the desire that they want to walk as nearly normally as possible On the other hand those whose rehabilitation was begun two or three years after the injury stated that their main objective was to get about after any method whatsoever Because of this psychological factor and also because it is the more difficult gait to master we believe the Step-Through gait to be the gait of choice whenever possible In addition, if these patients are received early after their injury and recovery is quite possible in the incomplete lesions it is thought to be more advantageous to teach the Step-Through gait first in the event that recovery does occur Thus with the progressive recovery of sensory and motor function the patient would not be obliged to learn a new gait which would be more suited to his returning muscle power

The Swing To gait is taught as a secondary method of walking In the higher lesions it was the gait of choice In the lower dorsal and lumbar lesions it offered another change of pace which would be valuable It is a faster gait but attracts more sympathetic attention to the patient s plight

When the patient s braces have been fitted, he is placed in a standard walker with crutch supports to acclimate himself to the vertical position and to learn of the principles of balance He is shown how small a deviation of the neck and shoulders is sufficient to change the balance He is then brought to a walking ramp Mirrors are used to check posture and to reflect his motion as he walks The ramp is approximately 36 inches wide and the railing is 37 inches high (Fig 13) It should be wide enough so that the pa

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tient must make use of his latissimus dorsi muscles in walking and not get into the habit of depending entirely upon the arm and forearm muscles

The patient starts the four point or Step-Through gait on the ramp by moving his right hand forward He then tightens his left quadratus lumborum muscle which elevates the hip and allows the left leg to swing freely If the patient still has use of his hip flexors he makes use of these to swing the left leg forward If the hip flexors are paralyzed he causes the leg to swing forward by a slight rotation of the trunk. This maneuver is repeated with the left hand and the right leg Proper use of the quadratus lumborum muscles is essential for a smooth appearing gait The patient must be watched carefully to prevent substituting the shoulder muscles for the quadratus lumborum if the latter is present This habit, if formed early is difficult to break as the patient becomes eager for progress and will strive to break his daily record by substituting

The patient is taught to turn around on the ramp walk backwards and sidewards so that when he is ready for crutch walking he has mastered coordination of hands and legs the principles of balance and the ability to move his legs in any direction in the horizontal plane In the absence of hip flexors and good quadratus lumborum muscles all the above can be taught by using the shoulder girdle pectoral and upper extremity muscles as substitutes

Crutch walking is essentially the same as walking on the ramp However the patient must learn to balance him

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that the patient may check his posture and movements as he walks. Ramp is 36 high and 37 wide and of varying length to suit existing available space

FIG. 13 Walking ramp used for beginners. Full length mirrors are placed at either end and a horizontal mirror is placed parallel so →

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that the patient may check his posture and movements as he walks Ramp is 36 high and 37 wide and of varying length to suit existing available space

FIG. 13 Walking ramp used for beginners. Full length mirrors are placed at either end and a horizontal mirror is placed parallel to
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	Date	Time of Performance
III Dressing Activities		
1 Undressing		
a) Removing clothing down to appliances		
b) Removing appliances		
c) Removing underclothing		
2. Dressing		
a) Putting on underclothing		
b) Putting on appliances		
c) Putting on rest of clothing		
IV Toilet Activities		
1 Getting on to toilet from wheel chair		
2 Attending to toilet needs (enemata, etc.)		
3 Getting from toilet to wheelchair		
4 Washing shaving brushing teeth, etc at basin		
5 Getting into bathtub from wheel chair		
6. Getting out of bathtub into wheel chair		

Summary

Group	I	II	III	IV
Impossible				
Possible, but slow				
Not normal but adequate				
Not normal but can be improved				
Normal in method and time				

FIG. 14 — *Continued*

ACHIEVEMENT TEST FOR SPINAL CORD INJURIES

Name Date of Injury

Diagnosis

Room Number

I Locomotion on Crutches	*Date*	*Time of Performance*
1 Opening and closing door		
2 Walking forward 45 feet		
3 Stopping quickly Changing Gait		
4 Walking sideward to right		
5 Walking sideward to left		
6 Walking backward		
7 Getting down on floor		
8 Getting up from floor		
9 Stepping up curb		
10 Stepping down curb		
11 Walking up standard steps		
12 Walking down standard steps		
13 Getting into automobile		
14. Driving automobile with special appliances (record driver s license when granted)		
15 Getting out of automobile		
II Locomotion in Wheelchair		
1 Getting from wheelchair to bed		
2 Getting from bed to wheelchair		
3 Getting from wheelchair to common chair		
4 Getting from common chair to wheelchair		
5 Getting from wheelchair to crutches		
6 Getting from crutches to wheelchair		

FIG 14.

	Date	Time of Performance
III Dressing Activities		
1 Undressing		
a) Removing clothing down to appliances		
b) Removing appliances		
c) Removing underclothing		
2 Dressing		
a) Putting on underclothing		
b) Putting on appliances		
c) Putting on rest of clothing		
IV Toilet Activities		
1 Getting on to toilet from wheel chair		
2 Attending to toilet needs (ene mata, etc.)		
3 Getting from toilet to wheelchair		
4 Washing, shaving, brushing teeth, etc. at basin		
5 Getting into bathtub from wheel chair		
6 Getting out of bathtub into wheel chair		

Summary

Group	I	II	III	IV
Impossible				
Possible, but slow				
Not normal but adequate				
Not normal but can be improved				
Normal in method and time				

FIG. 14 — *Continued*

FIG. 15a. One crutch used in stair climbing Patient is taught to use crutch under either arm with rail on opposite side. The foot to go up first and the foot to come down first must be on the side of the →

self in this more mobile state The patient has been given crutch exercises long before he is allowed to use them These exercises consist of learning to move crutches in the proper arc from rear to front rather than with a sidesweep, learning how to catch himself by throwing his crutches ahead and behind his weight how to balance with one crutch, and the proper way to hold and use crutches

The Swing To gait is taught in the same manner on the ramp and then the patient is given crutches In addition exercises on parallel bars are given to strengthen the arms for swinging the body When on crutches the patient is closely followed by an attendant until he has gained confidence The Swing To gait consists of virtually raising oneself by bearing down on hands with the forearm muscles to clear the feet from the floor and then by continued bearing down dragging the body up to the crutches The crutches are then placed ahead of the patient and the maneuvers repeated In the Swing Through gait the body swings through and beyond the crutches

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rail In climbing stairs, the crutch remains on lower step In descending stairs the crutch goes down first.

FIG. 15b Stair climbing with two long leg calipers. Patient starts at left side of stairs, feet together hands grasping rails. Right leg is swung diagonally up to next step Patient pulls himself up onto his right leg, allowing left leg to follow He then moves to left side of the stairs and repeats maneuver on the next step

FIG. 15c. Descending stairs with two long leg calipers. Patient starts at right side of stairs, feet together hands grasping rails at level of next step. Right foot should be placed so that ball of foot and forward edge of heel are beyond edge of step Left leg is swung diagonally down to left side of next step Right leg follows If patient has difficulty getting right foot down off step, he turns body toward left rail so that hip flexors and/or gravity may help (Courtesy of Journal of Neurosurgery)

FIG. 16 Opening door from crutches Patient is taught to open and close door from both directions. Here patient's right hand is on →

When the patient has become proficient with his crutches he is given an achievement test (Fig 14) against time While he has been preparing himself for ambulation he has also been taught while in the wheelchair stage to dress and undress to get in and out of bed into wheelchairs, to enter and leave a tub from a wheelchair, to get on and off a commode from a wheelchair, to get in and out of common chairs in and out of a car from a wheelchair He is also taught other common every-day activities necessary for bowel and bladder care such as preparing and administering of his own enemata, etc When he has reached the stage of crutch walking he is taught how to do these same things from crutches in addition to walking up and down stairs (Fig 15) curbs, walking forward, backward and sidewards opening and passing through doors, closing it behind him (Fig 16) getting up off floor entering and leaving wheelchair (Fig 17) changing gaits and applying his appliances His time for performing these various acts is recorded and he is then checked regularly for improvement

After he has shown improvement, the patient should be interviewed with the idea of obtaining his educational social and vocational background With these records and his medical history the patient can be approached as to his desires for a future occupation Vocations and positions are obtained after consultation with the patient and an explanation of his handicaps and the probable extent of recovery

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door knob as he pulls door toward him. Right crutch has been taken from under arm so that door will have room to swing Beginners are advised to side step to left to give clearance for the door rather than attempting to balance on the one crutch This illustrates value of pre ambulatory crutch exercises.

FIG 17a. First position in getting into wheelchair from crutches. Patient walks straight up to chair straddling it with crutches. The crutches are placed against the wall as patient steadies himself with hand on arm of wheelchair

FIG 17b Second position in getting into wheelchair from crutches Holding onto arms of wheelchair patient has mover legs back and to the left. He then puts both hands on right arm of wheelchair and allows body to pivot around into chair Getting up from chair to crutches is the reverse except that right hand goes behind patient to left arm chair as in starting position

are made known to him Thus with the patient ambulatory and with a goal to strive for he is spurred on to add to his independence and self respect

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Chapter VIII

ORTHOPAEDIC PRINCIPLES AS APPLIED TO THE REHABILITATION PROGRAM

R. NELSON HATT M D

INTRODUCTION

The mortality and morbidity of these once rather hope less casualties has been so greatly reduced through modern urological and neurosurgical treatment that as a result of war sustained injuries we are now confronted with a group problem rather than with one of the occasional individual survivor That the paraplegic can be made ambulatory and more or less self sustaining is an established fact

The immediate treatment of spinal fractures with or without cord injury is so well established that it needs little more than passing mention However the general principle of avoiding flexion of the injured spine at all times with transportation in the supine position is all too frequently violated When these injuries are further complicated by cord damage the immobilization in plaster should be avoided since decubiti, especially in the sacral region may occur within an exceedingly brief period The pneumatic mattress with blanket rolls is perhaps the best method of treatment The Stryker frame is also a well conceived means of permit ting the proper handling of paraplegics

Physically the rehabilitation problems are not unique and in general principle vary not greatly from those met

with in the treatment of victims of severe poliomyelitis or cerebral birth palsy Partial or total loss of sensation and the tendency to pressure necrosis are the chief points of difference physiologically, while adult mental patterns psychologically are either an asset or a liability

The program of reconditioning begins as soon as the critical stage of injury has passed and the prognosis for survival seems apparent. At this period it is essential to prevent fixed deformities due to disordered or disconnected neuromuscular control Reconditioning of the shoulder girdle and upper extremities is most important, since future ability to carry on ambulation and self help depends upon the compensatory development of these parts (assuming of course, the lesion to be below C4) As a rule, spinal fractures and dislocation should be maintained in some type of fixation until healing has occurred This does not preclude the daily routine of upper extremity exercises and calisthenics adapted to the supine or prone positions The prevention of fixed contractures of the anaesthetic lower extremities is best done by frequent changes in posture and supportive splinting nonrigid in character The hazard of producing decubiti with rigid splints needs only mention The ambulatory part of the program begins when the general health status is consistent with the rather strenuous physical effort required in assuming a vertical posture Decubiti per se are not a contraindication unless they occur in areas subjected to further pressure from braces

The orthopedic surgeon trained in the mechanics of locomotion and in the construction and application of prostheses quite naturally assumes a responsible role when the ambulatory phase is reached Anticipating the date when braces will be required tracings and measurements are made

by the orthopedic mechanic. Fitting is accomplished and the finished product is kept hanging by the bedside as a morale factor

Exercises in posture and balance using stall bars parallel bars or standing with crutches initiate the stage of ambulation The patient is also given instruction in seating himself and arising from wheel chair On the mat he is taught the mechanics of falling crawling and arising without assistance. Confidence gained through these exercises is a valuable asset in the next phase when progression with crutches must be made The first step is simple tripod locomotion the crutches placed well in front forming two legs, and the braced lower extremities in the third In this position the feet are dragged forward As soon as this is mastered, step-crutch movement is taken up one crutch and one foot being moved synchronously The third mode swinging through is the last to be developed since it requires both balance and timing The crutches are placed well in front as in tripod walking but instead of dragging the legs up to the crutch position the feet are swung clear of the floor to a point well in advance of the crutches As the feet contact the floor a thrust on the crutches propels the body forward and the pendulum like swing of the legs begins again This mode gives speed and when proper skill has been acquired can be done with little effort or fatigue

SURGICAL CONSIDERATIONS AND PROCEDURES

Contractures of the fixed or spastic variety prevent the satisfactory application and use of braces When conservative measures have failed to improve or control contractures surgical correction becomes imperative

OPERATIVE CONSIDERATIONS AND PROCEDURES

In certain cases where bone damage has been excessive and satisfactory spontaneous repair has not taken place leading to instability and increasing deformity such as kyphosis or lateral deviation stabilization by means of fusion or bone grafting may become necessary The Hibbs type of fusion is the method of choice in the dorsal region, unless there is a marked loss of spinous processes or laminae which may have resulted from laminectomy in which event bridging with cortical bone is necessary In the lower dorsal and lumbar area the Albee technique, using the tibial graft is preferable because of technical simplicity and rigid fix ation

From the standpoint of surgical treatment, lower ex tremity conditions fall into four clinical categories depending upon cord levels or completeness of the lesion

1 Spastic contractures *without* mass spasm
2 Spastic contractures associated *with* mass spasm.
3 Flaccid contractures
4 Incomplete palsy with spastic or flaccid inbalance (The above is in descending incidence based upon a series of one hundred fifty cases)

In Groups 1 2 and 4 spastic adduction knee flexion and equinus is the most common combination although any one of the three deformities may occur alone

Selective neurotomy of the motor innervation (Stoffel) releases spastic contraction Since it does not produce total paralysis, the extent can be controlled and the effect is per manent The technique is relatively simple but demands an exact anatomical knowledge including that of intraneural topography

Experience gained over a period of years in carrying out the procedure of cerebral birth palsies has shown that tendon lengthening of the neurotomized muscles should practically always be done because a secondary fibrotic contracture occurs, especially in the calf group of muscles

A brief description of operative technique as applied to regional contracture follows

A. Adductor Spasm

Operation — Obturator neurotomy with tenotomy of adductor longus

The hip is flexed 45 in the maximum abduction obtainable. Incision is made over the adductor longus from origin distally 7 cm dividing the deep fascia A blunt dissector raises the tendon which is then completely transected As the muscle belly retracts the sensory branch of the anterior division of N obturator can be seen lying upon the underlying adductor brevis Using this branch as a pilot, the main trunk with motor rami are easily picked up proximal to the vascular plexus which causes troublesome hemorrhage when disrupted Retraction upward (using a Cushing retractor) exposes the nerve nearly at its exit from the obturator foramen The trunk is clamped with a haemostat and divided The posterior division usually is not visualized, but may be crushed as it leaves the adductor canal The proximal stump of the anterior division is caught in the closing sutures of the fascial layers to prevent possible reinnervation

B Hamstring and Calf Spasm

Operation — Tibial neurotomy

Tenotomy of hamstrings and Achillis (triceps sural) lengthening

OPERATIVE CONSIDERATIONS AND PROCEDURES

In certain cases where bone damage has been excessive and satisfactory spontaneous repair has not taken place, leading to instability and increasing deformity such as kyphosis or lateral deviation, stabilization by means of fusion or bone grafting may become necessary The Hibbs type of fusion is the method of choice in the dorsal region, unless there is a marked loss of spinous processes or laminae which may have resulted from laminectomy in which event bridging with cortical bone is necessary In the lower dorsal and lumbar area the Albee technique using the tibial graft is preferable because of technical simplicity and rigid fixation.

From the standpoint of surgical treatment lower extremity conditions fall into four clinical categories depending upon cord levels or completeness of the lesion.

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3 Flaccid contractures
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on the opposite oblique the cutting edge blade is turned posteriorly with section of this portion of the tendon A third puncture 3 cm above transfixed the tendon transversely and turning the cutting edge anteriorly sections the middle fibers The foot is then forcibly dorsi flexed the tendon elongates but does not lose continuity The necessity for oblique rather than transverse division has been adequately explained by J Warren White s investigation and demon stration of the development rotation of the component fibers Postoperatively a plaster boot is applied in the cor rected position and left on for four full weeks when it may be bivalved and used as a night plaster for another month

C Flexion Contracture Hips

When hip flexion is purely a matter of psoas spasm it is most commonly associated with mass spasm and a complete cord lesion as discussed under Rhizotomy in the neuro-surgical chapter In the occasional case detachment of the iliopsoas at its insertion may be required This is best done through a posterior approach subperiostally

A comparatively few cases of fascial hip contracture with fixed internal rotation occur These may be classified as Hip contracture — fascial

Operation — Fasciotomy (Soutter)
Gluteus medius release (Durham)

Incision from anterior superior iliac spine obliquely to the anterior aspect of trochanter major The anterior margin of the ilium is stripped subperiosteally from the anterior superior to anterior inferior spine and may be carried back laterally along the crest for two or three inches if necessity arises Thus the M tensor fascia lata the sartorius and adjacent fascia are released and slid downward

In prone position, the knee joint is flexed 90 The scalpel handle is placed firmly into the angle between thigh and leg and held in position as the leg is extended This marks the level of origin of the branches to the calf group A 5 cm incision is carried transversely over the popliteal space through skin and superficial fascia Somewhat lateral to the midline underlying the deep fascia, is the short saphenous vein which is used as a guide to the N tibialis Next the deep fascia is split in a longitudinal direction just medial to the vein and retracted laterally The popliteal fat is separated with scissors exposing the nerve Hemostasis must be complete, since a little bleeding will obscure the nerve bundles and make identification difficult The tibial component of the sural nerve lies superficially and if pinched gives no reaction The medial gastrocnemius branch is dorsal and medial to the sural while the lateral gastrocnemius and dorsal soleus are dorsolateral These bundles are now picked up with a small dissector or other like instrument and sectioned according to the degree of spasticity

Usually one half of medial gastrocnemius and the entire dorsal soleus will be sufficient At times all three may be sectioned Through the same incision tenotomy of the ham string group is easily accomplished The proximal ends of the divided nerves are closed in the fascial layers The Achillis tendon (tendo-calcaneus) is *lengthened* by the subcutaneous *triple hemisection of Hoke (unpublished)* It is performed with a tenotome in the following manner With the tendon on stretch the skin is punctured on the medial surface about 2 5 cm above insertion of the blade transfixing the tendon obliquely to its outer border turning the cutting edge anteriorly the cut is completed A second puncture approximately 3 cm from the first transfixed the tendon

tunnel fixing the joint firmly Multiple segments of cancellous bone (from the tibia) are packed in at the joint line Closure is made in layers and plaster applied from toes to mid thigh Weight bearing in plaster begins at eight weeks and fusion is usually solid at ten to twelve weeks

E. Braces

Opinion concerning both material and construction of braces varies greatly We have the advocates of steel dur aluminum or alloys heavy versus light construction, ring lock versus spring or bull locks stirrup versus caliper shoe connections laced or strap and buckle thigh cuffs knee caps or no knee caps and a variety of pelvic bands limited only by the imagination of the prescribed or the facilities of the fabricator Furthermore the paraplegic patient may be a tempermental fellow who is inclined to blame his failure to make adequate progress on the quality of the prosthesis he is obliged to use All these factors add to the confusion of mind in the corps of people who are attempting to carry on the program

Without resorting to absolute dogmatism, perhaps one might clarify the brace situation on the following points

1 Standardization of brace materials is desirable
2 Standardization of joints and locks is feasible and desirable
3 Standardization of types and weight is as illogical as would be the standardization of spectacles i e the individual must be fitted according to his physical needs In most instances a heavy patient will require a more heavily constructed brace than the slender fellow and the spastic will need a more rigid support than the flaccid

If fixed internal rotation persists division of the anterior half of the gluteus medius insertion at the trochanter (Durham) will effect correction

Group 3 comprises a small percentage and is of course, the result of caudal and not cord involvement They are included because of associated urological and nursing problems Complete lower extremity paralysis naturally demands braces however a not unusual case will have good knee control but absent leg musculature or a weak quadriceps which is incapable of stabilizing the knee because of the flail ankle In this situation fusion of the ankle joint will emancipate the patient from braces and enable him to operate an ordinary automobile — not possible with a flail ankle.

D Flail Ankle

Operation — Fusion (Central Graft)

A slightly curved incision from mid leg to neck of talus The anterior aspect of tibia is exposed subperiosteally and the tendon of tibialis anterior is either retracted or divided. The ankle joint is completely opened the synovia dissected, and the articular surfaces completely destroyed with osteotome and curette *leaving the osteo-cartilaginous chips in situ*

With motor saw a graft 7 cm in length by 1 5 cm in width is removed from the anterior tibia to a point 4 cm above the ankle joint Using a bayonet osteotome a tunnel is made through the medullar canal of tibia well into the body of talus, relationship of the foot to the leg being maintained at 95 or in case of quadriceps weakness at 100 110 The bayonet is withdrawn and the graft which has been beveled at one end is inserted and driven through the

tunnel fixing the joint firmly. Multiple segments of cancel lous bone (from the tibia) are packed in at the joint line Closure is made in layers and plaster applied from toes to mid thigh Weight bearing in plaster begins at eight weeks, and fusion is usually solid at ten to twelve weeks

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In lesions above the mid dorsal area, a back support attached to the lower extremity braces with locking hip joints is practically a *sine qua non* to ambulation Many lower dorsal and most lumbar lesions have sufficient abdominal and pelvic stability to not require additional support but a few will need a pelvic band or breeching strap A certain number of cases acquire stability as time goes on and eventually get about well in lower extremity braces only The question of shoe attachment is somewhat mooted, and here again the individual must be considered The stirrup type gives greater stability but adds to the difficulty of placing the foot in the shoe The caliper permits putting on and taking off the shoe with ease and is preferable in most instances

Concerning back braces unattached to the lower extremity supports the simple quadrilateral with corset front is apt to be quite as satisfactory as the more elaborate modifications The patient should be instructed in the ordinary care of his apparatus including minor repairs and adjustments

In the matter of crutches the ordinary adjustable type meets most requirements rarely modifications may be needed in case of upper extremity impairment.

We may conclude that given the benefits of professional teamwork, the paraplegic patient may be salvaged, and take his rightful place socially and economically

Chapter IX

PSYCHOLOGICAL CONSIDERATIONS

DOUGLAS A THOM M D

CHARLES F VON SALZEN M D

It is estimated that at the cessation of hostilities there were approximately 1400 paraplegic patients in Army hospitals This represents the largest number of such cases that has ever been under the care of any one agency or institution at the same time This group of cases provided an unusual opportunity to make observations and carry out diagnostic and therapeutic measures which heretofore were not available

These men have been salvaged by modern medical and surgical skills which were not available during World War I Rapid and efficient evacuation of the wounded measures to counter shock sulfonamides, penicillin and streptomycin and greater knowledge of the nutritional management of of these patients have permitted many of these men to carry on within their physiological limitations who formerly would have perished.

Studies and observations were undertaken to determine the general nature of the problems of the paraplegic patient in Army hospitals An attempt was made to outline some of these major problems both medical and psychological and consider the methods employed to cope with the paraplegic patient and his environment These studies were car

ried out in an effort to contribute something that might be of value to those who will be charged with the care of these patients in Veterans Hospitals and civilian life. If these patients are to be something more than a living memorial to the skill of the physician and the advances in surgery their rehabilitation from this point on must be recognized as an important challenge. Suggestions as to how best meet this challenge are made with due appreciation that they are tentative and subject to change as we learn from experience.

Investigation of the literature with reference to paraplegics yields little material that is relevant to the situation with which we are confronted at the moment. Suggestions for the care and medical treatment of the paraplegic have been reported from time to time, but the present necessity for the treatment of this relatively large group of cases of both military and civilian origin calls for greater understanding and consideration of the individual as a whole. This demand has stimulated the ingenuity of the medical officers and certain techniques have been devised and have been reported which will take precedence over those of the pre-war era. The psychological factors in adjustment of the paraplegic are recognized as an important aspect of the total situation which has been completely overlooked heretofore.

The group studied represented a fair sample of the Army population in general. It consisted of 228 male soldiers at Halloran General Hospital and Thomas M. England General Hospital, 15 of whom were officers and the remainder enlisted men. The ages ranged from 19 to 45, 77 per cent of the patients being 30 years old or younger. General mental ability of the group as determined by AGCT scores on induction, was distributed normally, ranging from low to high

scores in typical fashion Educational background ranged from five years of elementary school to graduation from college the preponderant majority of men having completed either elementary or high school Over $\frac{1}{3}$ of the men were married In approximately $\frac{3}{4}$ of the cases their pre war civilian occupations required the use of their legs Of the remainder engaged in sedentary occupations about $\frac{1}{4}$ were still students

All the cases were traumatic in origin except for one case of poliomyelitis and one of neoplasm Three of the patients were amputees as well two involving a lower extremity and the third case an upper The duration of illness at the time of study ranged from three to 27 months the average being slightly over $9\frac{1}{2}$ months Approximately six per cent of all cases had been disabled less than six months 74 per cent between six and 12 months and about 20 per cent for more than 12 months

The cord lesions ranged from concussion to transection the levels of injury from the fourth cervical segment to the sacral segments and including several cases of cauda equina injury There were 16 cases of injury to the cervical cord 112 cases with injury to the dorsal cord and 55 cases with injury to the lumbar cord The ratio of incomplete to complete cord lesions was a little more than one and one half to one

The group studied included patients in the earliest stage of recovery the intermediate stage and the late stage In the earliest stages are those patients confined to bed requiring suprapubic or indwelling catheters treatment of decubitus chemotherapy and nutritional management In the intermediate stages are those patients who are able to be out of bed for a large part of the day in wheel chairs and

who are beginning to learn ambulation by means of crutches and braces In the late stages are those patients who can walk with braces and canes or with canes alone About ¾ of the patients had either reached or had gone beyond the stage of beginning ambulation Almost all patients had learned some self-care

The method employed in this study consisted of psychiatric interviews of one to one and one half hours duration, conferences with physicians nurses, attendants and technicians engaged in the care of the patient Observations were made of the group during daily activities daily rounds were made with the attending medical officer informal chats with the patients and general informal social intercourse were all employed to elicit information Projective techniques were attempted but discarded as being of less value than the direct interview A questionnaire for the expression of certain opinions discussed below was also used at one point in the study

The course of paraplegia can be divided for convenience into three phases These are not distinct or well defined but they tend to merge into successive phases The first phase is that immediately following wounding and lasts for approximately six months This is the phase during which shock and infection are combatted, decubitus ulcers form and are healed nutritional management becomes difficult and often great weight loss and inanition occur Physiological balance is difficult to establish especially where open bed sores result in massive losses of serum protein and body fluids During this phase the psychological factors are invariably of such a nature as to exert a negativistic attitude adding to the difficulty of accomplishing the desired results

The second phase which lasts approximately six months

is that in which ambulation is begun measures to relieve pain instituted and acceptance of the disability begins It is during this period that motivation becomes most important since the success or failure of future efforts depends upon the attitude the patient develops during this period

In the third phase which the patient enters usually between the twelfth and eighteenth month following injury medical and surgical procedures become of lesser importance and rehabilitation of greater importance During this phase the patient can care for himself to a great degree He can get out of bed into a wheel chair without assistance can spend most of the day without being confined to any particular place go home for brief visits, and through one means or another remain relatively free of soiling with urine. When his braces are put on for him he can walk around with crutches moderately well although he is very uncertain on steps or steep inclines

The patient who has been injured less severely can in this phase take care of most of his needs and is relatively independent These patients who plan to return to school can face the future with equanimity The majority of patients however who were employed before the war in jobs particularly those requiring the full use of their legs are concerned about financial security and job placement

The chronic aspects of cord injuries which concern the patients fall into six major spheres mobility bladder function sex function bowel control other physical complications and future economic status It is difficult to prognosticate motor function in any one case even in those cases of high transverse lesions where much can be hoped for from braces and crutches Until nutrition and weight are restored and the strength of upper extremity back and ab-

dominal muscles fully developed it would not be sound to give a bad prognosis It is during this period that the patient should be instilled with the will to recover and the desire to walk again and to overcome his first feeling of dismay and discouragement when he discovers what an arduous and difficult task lies ahead

By means of rubber urinals Cunningham clamps athletic supporters automaticity and other techniques he can manage some degree of control over his urinary output The psychological aspects of these substitutes for normal bladder control must be weighed carefully and discussed with the patient He feels very self-conscious and unless he is given an opportunity to discuss his feelings he will seldom volunteer information His fears are readily verbalized, however and easily overcome by rationalization suggestion or persuasion

The bowels offer less difficulty since most patients develop constipation which must be treated with enemata, suppositories or mild laxatives Possibly some automatic bowel control can be anticipated

Probably all paraplegic patients will find some change in sexual function Those with the least damaging injuries describe a diminution in sensation and less persistence of erection Others who lack bladder control find they void rather than emit semen Some with transverse lesions can have erections and sexual contact although they experience no genital sensation Much remains to be learned of the sexual function in paraplegia Artificial insemination, for example, may offer hope to a married couple desirous of having a child Adopting of children should always be given consideration as it well may prove a very satisfactory solution of that problem of the married group The emo-

tional value of giving expression to secondary erogenous zones must be investigated Most single men do not intend marrying However, there is no reason to believe that marriage based on mutual understanding and need and willingness to forego the sexual act may not be successful Although this can be now of small comfort to the paraplegic patient it can be reserved for future consideration

The other physical complications incidental to paraplegia are of great concern to the patients Recurrences of bladder infections the tendency to stone formation breaking down of repaired decubitus ulcers, intercurrent infection all contribute to his ruminative obsession with bodily functions These complications require skillful medical and surgical management It can be expected that as the body becomes stabilized the physiological complications will become less marked and those which persist can be more readily accepted However at best they will always be present even if reduced in number and intensity It is an extremely important part of therapy to help each and every individual patient to learn how to live with these handicaps with the minimum amount of inconvenience and resentment

The majority of these patients if they make any attempt to formulate future plans fail to deal with the reality of the situation and overlook the limitations imposed by their handicaps All too frequently they plan to engage in occupations that are totally incompatible with the residual physical disability During the early stages of the rehabilitation program they are disinclined to make any plans whatsoever, and actually indulge themselves in a world of fantasy Since one must accept the postulate that a happy life is also a full and productive life it is obvious that every effort must be made to contribute something to these men above and

beyond the privilege of a leisurely existence There appears to be an intellectual appreciation of this need which they find difficult to face frankly and unwillingness to take the essential steps to bring it about.

The type of onset in paraplegia is of considerable psychological importance The symptomatology and incapacity are violently incurred and are at their height at the time of injury A reasonable expectation can be held that the condition will not become worse with time The non-progressiveness of the traumatic injury, as compared with a chronic degenerative disease such as multiple sclerosis is certainly an important factor in the adjustment of the patient He is not necessarily subjected to the extreme emotional swings which occur with the remissions and exacerbations of an active disease process At the same time he is denied the opportunity to rationalize and digest the psychic trauma associated with the physical disability The psychological situation of the man suddenly and unexpectedly incapacitated by a gunshot wound is quite different from that which confronts the patient suffering a spinal cord disease which is insidious in its onset. The ego must absorb at one time wounding shock, infection, prolonged illness, as well as crippling of the body sex functions and bladder function It is therefore not surprising that the personality is subjected to a serious psychic trauma This realization can not be reached without profound disturbance of the ego or without considerable situational depression

These men prior to injury were finely trained in excellent physical condition and totally independent Concurrently with the injury came total dependence, dependence upon others for transport sustenance, and of the disposal of bodily excreta Despite the fact that they found them-

selves infantile in their dependence psychiatric syndromes in the usual sense of the word are not present

Although there is no personality trend or pattern which is characteristic of the group it is true that almost half of the patients reveal some manifestation of depression either episodic or prolonged This is always situational and related directly to concern over the disability There is no significant difference in reaction between those who had been injured in the performance of duty and those injured accidentally Nor is there any significant difference in those who had been injured along with several others as occurs in battles mine accidents fires etc and those who were injured while alone as might occur in an automobile accident Loss of consciousness at the time of injury did not alter the resulting picture These patients are not disposed to express or show evidence of guilt feelings over the injury and few project the blame upon others Most of the patients are inclined to consider themselves lucky to be alive Only occasionally do patients indicate that they are ashamed of their physical appearance

In general the reaction to the disability is better in those patients in whom the pretraumatic personalities were sound Patients whose pretraumatic personalities were characterized by extraversion high feeling tone and little intellectualization reacted well to the disability Patients who were part of a stable closely knit family constellation reacted well to the disability especially if the patients played a minor dependent role in the family Patients whose pre traumatic personalities were characterized by intense personal effort and ambition experienced greater difficulty in adjustment They became depressed easily by slowness in progress and readily gave way to anger and irritability Patients in whom psychopathic

traits were dominant reacted most poorly to the disability This group was most demanding least understanding of the needs of others and most subject to frustration Their behavior was likely to be characterized by episodes of tantrums profanity and abuse of the nursing and attending staff while in the hospital and marked irritability with the family when at home

Notable in the adjustmental process of these patients is an increase in their feelings of dependence upon others The grossly debilitating nature of the injury establishes initially the necessity for dependency but soon this tends to persist beyond the limits of medical necessity and appears rather as a personality phenomenon in itself Although the patient does not recognize and consciously accept the fact that much of his former world now has to be mediated through others he has inescapably come to lean upon others even more than his disability requires The hospital is regarded by many as the one dependable refuge where their needs are best understood and most completely satisfied It is not uncommon to find the patients in military hospitals even more disturbed than resentful when they overhear conversations among duty personnel about being discharged They fear they might be abandoned and not infrequently show marked disturbance as a result of changes in the personnel who attend them This may be related to a doctor nurse or some member of the family who is temporarily leaving the home for a vacation

Although the hospital satisfies this general insecurity and dependence proximity to home is a factor probably of equal importance Receiving frequent visits from their family and, in the case of ambulatory patients going home for weekends also offer the patient the emotional solace of easy transference and identification However this is not free

from psychological hazards The patient's reactions to obviously over indulgent pity and regard whether it be from parents or from people in general, is not a pleasant one It is as though the patient reacted not to the pity offered him but rather to its implications namely the disastrous and hopeless nature of his predicament On the other hand he reacts just as unfavorably to neglect and disregard Although it would be extremely difficult to prescribe a formula for appropriate family behavior and attitudes toward the paraplegic, general tact can not be overemphasized

Perhaps the most outstanding single expression of their dependence is revealed in the way these patients consider the future At least half of them tend to reject completely any serious attempt to plan for the future Others who are willing to discuss the problem are firmly convinced and express the opinion that they believe it is too early to make plans when the final outcome of their case is still to be determined This complete absence of any attempt to solve the problems of occupational adjustment and lack of interest in the future development of their economic security appears to be associated with their implicit acceptance of themselves as privileged characters whose maintenance will be accomplished by hospitalization, compensation and perhaps a solicitous family Among those who have given their future plans and adjustment to life any consideration whatsoever the more aggressive or outgoing personalities cling to their dependence by wishful thinking and fantasy They are disposed to daydream about some fantastic scheme a fairy godmother or some mythical business partner who will arrive on the scene and from whom financial security will be achieved

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One notable exception to their feelings of dependence concerns their attitude towards marriage Although most of the patients remain silent on the subject those who do discuss it obviously continue to regard the woman as the non-dominant dependent partner in the marriage relation ship even though they recognize the enormous help a wife could offer them in their present condition

Although frustrating experiences of the patient may vary from the most trivial slight to a complete blocking of a variety of desired goals, probably the most frequent and most important of this type occurs in connection with daily rou tine activities Typical of these as observed in hospitals is having experiences where they have to wait their turn for something or other being refused what they want dissatis faction with meals lack of attention from the doctor or nurse, or some member of the family The reactions to these frustrations vary with the personality of the patient But usually behavior of this type is found in the more immature and more dependent, and occurs with greater frequency Emotional lability is the cause of many unpleasant scenes The lack of normal emotional control is again evidence of a certain regression that is associated with dependency Co-incidental with their increased feelings of dependency there appears proneness to become aggressive There may be out bursts of rage, temper tantrums excessive irritability im potent anger brought on by frustration of aims Any evi dence of indifference on the part of those responsible for care is invariably exaggerated by these patients and brings on bitterness depression and temper displays One patient in a fit of rage threw his urinal another became negativistic and refused to eat. Still another patient who was refused a hypodermic sulked and would not get out of bed for his

job within the next year or two or they want it to be near their home they expect to earn big wages, and most of them entertain an idea that their recovery will be well beyond what the facts of the situation justify As one might expect there is considerable variation in the attitude of these men and there are those who plan their adjustment to the future along more realistic lines Some of them express the desire to start right in learning a new vocation They are eager to embark upon some plan of training which will prepare them for specific civilian jobs Inasmuch as most of these men received their disability during military service where the question of compensation is an important factor the major obstacle to realistic thinking about the future in terms of the development of relative independence is the patient s rapidly growing uncertainty and anxiety about what he may expect from the government in the way of compensation The amount of disability compensation and its permanence are sources of deep concern to him Either consciously or unconsciously he is afraid that every encouraging sign of medical progress will bring in its wake decreased disability compensation The more progress he shows the more he feels thrust upon his own without any adequate guarantees from the government upon which he can depend

With the medical picture as involved as one finds in the paraplegic and the patient s realization of the difficulties of competing in the open labor market it is easy to appreciate the patient s fear of striving in the direction of recovery and independence This consequent conflict which arises between the desire to reach maximum improvement and his tendency to cling to his economic security is a serious barrier in creating the motivation which is essential to the best therapeutic results

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exercises It is easy to recognize that certain of these patients react like spoiled children and express their resentments and grievances in an unrestrained manner

Another common source of frustration is the great difficulty the patient soon experiences in connection with learning to use braces and crutches He frequently loses interest when his progress slows down and develops a protective apathy in his childish rejection of the major goal It is a real problem to maintain a high degree of motivation among these men Patients who begin courses of training also frequently lose interest and in general may be said to show an inability to concentrate and hold their attention to any one thing for any length of time

It is probably safe to say that most of these patients believe that some day they will enjoy a complete recovery of their lost functions They cherish this undying hope and it is nurtured in several ways

In contrast to the amputee who is confronted with the visual fact of loss of an extremity the paraplegic sees his legs and knows only that they do not move Sensory changes are interpreted wishfully The appearance of pain, previously regarded as unpleasant is now welcomed as a sign of returning function It is so very difficult for medical officers to make an accurate prognosis that so far as the patient is concerned, the future remains always pregnant with the possibilities of improvement The future, in short is not definitely outlined, it remains structureless and thus provides the patient with a fertile ground for the projection of his wishes

This fantasy of future structural integrity is nurtured not only by the inability to provide the patient with a dependable prognosis but, paradoxically enough also by

prognoses at either extreme of the optimism pessimism scale The over-optimistic medical officer who places a premium on the patient s present comfort rather than future adjust ment to the incapacities he will suffer obviously encourages the self-deceptive process already begun by the patient him self On the other hand a hard bitten medical officer who right from the start declares flatly to the patient that he will never walk again frequently has an equally encouraging effect on the patient s rationalizations about the future Should such a prognosis be wrong and some small gain in motor power be achieved the patient at once develops the belief that if the doctor was wrong in any one prediction he must be all wrong and that complete recovery is now possible It appears that the presence even of only one such a case is enough to infect a whole ward with such over-optimistic rationalizations

The imbeddedness of these unrealistic attitudes about their capacities in the future reveals itself also as patients begin to ambulate again They resist the use of the swing through gait because they never walked that way before Similarly when they are given demonstrations or shown movies illustrating the technique of brace and crutch walk ing they are impressed not so much by the fact that ambu lation has been attained but rather by the awkwardness of the gait The distastefulness of the reality situation is ex pressed by resentment on the part of the patient when confronted by someone who has been walking in this fashion for years

The patient s dependence upon time rather than effort for his improvement is still another expression of his autistic thinking He tends to believe that time itself will result in the recovery of lost functions If I knew I were not going

to get better I would work harder on my exercises ɪs the typical attitude. The lazy confidence the patient places in his hopes and expectations in many cases militates against the energetic, highly motivated adjustment necessary to realize — even in part — these desires It ɪs by no means automatically or willingly that the patient accepts his period of exercise or mat work There are many psychological hurdles which the doctor nurse, physical instructors and other personnel have to overcome before the patient ɪs well embarked upon the rehabilitation program

Inasmuch as the overall care of the paraplegic is so demanding continues over such a long period of time, and requires a large number of highly skilled specialists the initial care for these patients must of necessity be organized with the hospital as a base of operation and other aspects of the convalescent program, such as recreational and occupational activities be initiated from the hospital It is therefore necessary to give consideration to the persons who for the patient represent society and to the physical structure of the surroundings which represent a substitute home for these physically handicapped individuals for a period covering many months There ɪs no more important part of the convalescent program than that of providing a healthy psychological atmosphere for this structure so that it will contribute to the patient s morale and give assurance of his maximum cooperation.

Personnel assigned to paraplegic wards should be very carefully selected The positive and negative effects of nurses and attendants upon patients are too well known to be repeated here The effect the patient may have upon the attendant, however ɪs not so well recognized It is a distinct emotional shock to meet with and care for paraplegic pa

tients This is usually experienced as a kind of depression One hears expressions such as I feel as if I m carrying around a heavy weight One person described anorexia for several days after assignment to a paraplegic ward Others admit easy irritability or a complementary attitude of excessive sympathy This shock wears off as the understanding of the condition is integrated into the psyche and as rapport is established with the patients The inadvisability of frequent changes of personnel is therefore apparent

The obligation of the physician to the patient goes beyond *specialized medical care* Although the most skilled neurosurgery genito-urinary surgery, plastic surgery medical and nutritional management are obviously essential there is a danger that the sum of these parts is taken to be the whole It is not sufficient to provide the most competent specialists An understanding physician to maintain liaison is still necessary The patient must be treated as a whole He needs someone with whom he can talk over his problems and on occasion he requires the assistance of a trained psychiatrist

The ward surgeon who comes in daily contact with the patient should be carefully selected He is required to apply urological neurosurgical and orthopedic techniques under the guidance of the attending physicians He must be oriented *in the field* of psychosomatic medicine and possess a working knowledge of dynamic psychology He must know his patients sufficiently well that he can comprehend the complex play of emotional coloring in his daily life He should be assisted by well trained social workers

The Hospital It is anticipated that not many patients will reach such a degree of improvement that they will be completely independent of the hospital Recurrences of

bladder infections formation of renal and bladder calculi, development of bed sores neuritic or causalgic syndromes will require repeated hospitalizations Even illnesses which are not unique to the paraplegic such as cardiovascular diseases anemia and surgical conditions, should logically be treated in the paraplegic center since these patients will always require a different type of nursing and medical care than the non paraplegic patient One would hesitate entrusting a paraplegic patient with coronary disease to persons not well acquainted with the complications incidental to paraplegia Since past medical history is of such importance it would be hoped that the patient could be hospitalized where his record is known.

It may be expected also that the facilities for training patients in specific occupations will find continued use long after the patient is discharged when a change in occupation becomes either desirable or necessary

The hospital therefore, should be designed not only for the immediate end of returning the patient to civilian life but also for making it possible for him to remain in *civilian life and pursue a fruitful productive and happy* existence

The question of the desirability of one paraplegic hospital centrally located to the majority of patients over several regional paraplegic hospitals requires careful study Patients want first of all the best in surgical and medical care They want to be so located that the best medical talent is available to them However the best is not of necessity the best known Nor is ability to handle a medical problem the talent of a few individuals It is entirely conceivable that equally good doctors and surgeons can be found for several paraplegic hospitals as for one paraplegic center

Proximity to home is a desirable feature It can be anticipated however that in time this will be of lesser importance to the patient than it is during this stage of his illness which has usually followed rather long separation from home Nearness to people is probably of more importance than proximity to home Patients want to mingle with people, they want to to be near and be able to share in normal activities shops theaters and restaurants There will be a continued need for accessibility of the hospital to the patients and to their wives and families and also *accessibility to inexpensive housing*

The building selected for the hospital should either be designed especially for paraplegics or if conversion is contemplated should be adaptable to the considerations which are unique to this group

Patients should be able to drive their cars into the hospital itself or into a courtyard with ready access to ramps and elevators These should be wide enough to permit easy movement Doors leading to and from the building should be controlled by an electronic device

Patients rooms should be semi private Private rooms tend too much to isolation, whereas rooms housing more than three patients are noisy and full of distraction The extensive use of glass for the walls of various rooms tends to counteract the feeling of confinement that frequently comes with hospital life The bed should be lower than the hosptial type bed so that patients can get into it from wheel chairs with a minimum of danger and difficulty The rooms should open into a communal day room equipped for recreation and social purposes This should have hand railings at strategic intervals Smaller rooms should be provided for classrooms shops music rooms and other esoteric pursuits An adequate

gymnasium with knee-level mats parallel bars stall bars, steps of different types traffic lights ramps and all necessary gymnasium equipment should be provided

Other features which should be considered include book shelves accessible to wheel chairs dining tables and writing desks under which a wheel chair may pass floor lamps pianos record players pool tables game tables telephones convenient to a wheel chair patient The latrines should be provided with wide doors electronically controlled, wash basins which can be used by the wheel chair patient and showers for sitting patients The height of the standard toilet bowel is satisfactory Hand railings should be provided to facilitate use

The hospital building should house the shops and training sections What types of training to offer will demand a good deal of study The shops furthermore must be flexible enough so that new projects can be instituted and less necessary projects discarded Certainly the hospital should be able to teach business practices banking radio and electronics drafting and mechanical drawing watch making and repair and other vocations which are compatible with wheel chair performance

The staff for this school should be drawn from the faculties of the best business and trade schools available Only in this way can one be sure of getting the services of the best instructors

The hospital rather than being an isolated unit might well be a part of a general hospital In such a case the same considerations must be observed, that is it must be planned especially for the type of case it will treat As part of a general hospital the obvious advantages are the elimination of any possible feeling of abandonment and the saving of

personnel The disadvantages to be weighed are the fact that the paraplegic service might be looked upon as an unwelcome subsidiary of the general hospital and might suffer accordingly

The paraplegic population is static and will not be substantially increased The group as a whole will consist of patients in a relatively similar condition just as it has in the past with quantitative and not qualitative differences Just as in the past all the patients incurred the disability at relatively the same time and passed through the stages of treatment of shock and infection the beginnings of ambulation, bladder automaticity and attainment of self-care so too will they complete their convalescence and together go on to the development of economic independence Together also will they later suffer relapses and require repeated hospitalizations

This maturation of the paraplegic patient requires a constantly changing program of reconditioning and rehabilitation to keep pace with the changing needs It also necessitates anticipatory thought to insure that those concerned with the management of the patients are not found unprepared for newly arising demands

The person in charge of reconditioning should be thoroughly experienced in the field of medical rehabilitation His medical knowledge should include knowledge of neurosurgery urology bacteriology nutrition physical therapy psychiatry and modern educational methods More than any other person he must possess vision breadth of viewpoint and intellectual curiosity It is his task to make it possible for the patient to progress smoothly from phase to phase until finally he is properly placed vocationally and readjusted to society His task will not be finished then,

however for he must follow his patients and when they return to the hospital critically evaluate his methods and when necessary provide new training techniques as indicated

The aims of reconditioning are four

1 To bring about the maximum improvement in physical tone and to promote ambulation and physical in dependence
2 To insure that each patient reaches the highest degree of self-care
3 To provide him with occupational training in the occupation for which he is best fitted
4 To assist him in the handling of personal and psychological problems

This division should consist of four Sections Physical Medicine, Occupational Therapy Education and Personal Services

The aims of the Physical Medicine Section are

1 To provide a program of physical reconditioning for bed patients as well as for ambulatory patients de signed to reduce spasm remove functional disabilities improve muscle tone and volume and provide muscle re-education
2 To give instruction in ambulation
3 To provide means to motivate patients concerning the desirability of physical reconditioning
4 To train a staff of persons engaged in physical re conditioning in the problems unique to the paraplegic patient

The Occupational Therapy Section will work in close cooperation with the Physical Medicine Section Its purpose

is to provide both diversional occupational therapy for short periods of time to patients who are unable to continue in vocational training and to provide functional occupational therapy to improve the functions of joints and muscles The functional program is by far the more important Care must be taken to insure that patients who can be better employed do not divert their whole interest and time to hobbies and crafts which have no industrial value

The Educational Section should be designed to offer technical and vocational training commensurate with the patients physical condition, prognosis aptitudes abilities and interests This Section must work in close liaison with the Personal Services Section and with the physicians in charge of the patient

Much has been learned about adult education in the Army Schools and the Convalescent Hospitals of the Medical Department This knowledge can be put to good use in the management of educational problems which are different from those found elsewhere Consideration must be given to several factors

1 The wide range of aptitudes interests intelligence levels and previous training
2 Frequent absences because of relapses or medical treatment
3 The physical status both present and future of the patient.
4 The variable demands of industry which may require shifting of emphasis from one subject to another

To meet this situation teaching must be individualized and so arranged that the patient may progress at his own rate Several schools have been organized along these lines

recently and it is believed that what they offer will be of value

The Personal Services Section will be concerned with all those personal, social economic and educational factors which make each patient an individual This Section must determine the psychological assets and liabilities of each patient, his aptitudes intelligence level, interests and problems It must ascertain from the patient s physician what his physical assets and liabilities are and determine how best to fit him into a productive niche in society It must survey the employment field to learn what types of jobs the patient can obtain so that he might be trained for that type of work It must work in liaison with the Education Section to insure that each patient receives training consistent with his abilities and the opportunities available to him. It must be familiar with the patient s home, his family and must be prepared *to assist in modifying unfavorable factors here Finally it* must be able to cope with poor motivation the depression and apathy so common to the paraplegic, his frustrations and his unreal type of thinking

This Section will therefore consist of a Mental Hygiene Unit of psychiatrists psychologists and social workers, in addition to personnel and employment specialists It will be the function of this Section to obtain through survey favorable job opportunities for the patient, to motivate him towards this goal and remove those factors both personal and environmental which inhibit motivation to insure that he obtains the training needed for the job and finally to follow him in the job for a sufficiently long period of time to insure success

The usual home is not adapted to the needs of the paraplegic patient Narrow stairways narrow doors, small bath-

rooms and other features which are entirely satisfactory to the well person may present hazards to the paraplegic which deter him from making full use of those assets he has retained An apartment house with an elevator may be somewhat simpler for him but over half of the patients live in private homes or flats which are not so equipped It becomes necessary, therefore to inquire into the modifiable factors of the home to see whether physical changes are feasible Several patients plan to build their own homes and this will require careful planning It would seem advisable for an architect to study the needs of the paraplegic patient so that he can design a livable house.

Steps should be eliminated as far as possible and replaced by ramps Doorways should be wide Tables and furniture should be designed with the paraplegic patient in mind Many of these patients will not marry Unless they live at home with parents they will therefore, be required to cook and perform other domestic duties The kitchen will require special treatment. Sinks cabinets and stoves must be designed for the special needs of the paraplegic. Most of the features described as important for the hospital can be adapted for the paraplegic's home

Many patients have already found their homes inaccessible If they live on the second or third floor of a flat or tenement they must be carried up and down stairs It is not difficult at this time while the knowledge of their sacrifice is still fresh in the mind to find someone to do this There will come a time however when it will be less easy to obtain this aid and they will then find themselves isolated to a greater and greater degree The problem of housing, therefore, becomes a social responsibility and it becomes the responsibility of whatever agency assumes the care of the

paraplegic This may require obtaining ground floor housing for patients and paying the differential rental Or it may require building for the patient until such time as he is self supporting and can assume the obligation himself

Since paraplegia is usually the result of violence compensation and pension considerations arise in the majority of cases This brings up the peculiar but understandable compensation neurosis Many evidences are seen of patients unwilling to make an effort to improve their condition because *this in their minds inevitably would be followed* by a lowering in disability pension and consequent lessened security A patient for example, fears that if his bladder function changes from complete lack of control to one of automaticity with relative dryness he will no longer draw pension disability for this Since such an improvement in bladder function may alleviate his condition very little he can see little advantage to himself in its attainment Such an attitude is understandable The patient faces a hostile world at a complete disadvantage, minus mobility and minus the driving force of libidinous impulses which help to motivate the uninjured person He must fall back upon modes of behavior of a less mature level Loath to accept a role of dependence his physiological demand for survival necessitates acceptance

An attempt has been made in this study to survey rapidly and yet carefully the problem of paraplegia resulting from the second World War and to view it not solely in the present aspect but also in its projection into the future Facts and findings have been combined with ideas hopes and in some instances, speculations It is not suggested that this plan we have described should be considered the final answer in paraplegia.

It would be unfortunate however if plans finally made to cope with this problem are made from preconceived judgments or on the basis of experience with other types of patients A careful first hand evaluation of the situation should precede conclusions It has been pointed out above that the literature does not offer a solution to the long term management of this group of chronic disabled patients This is not because we have not for years had to face the problem of the management of the chronically disabled but because for the most part domiciliary custodial care mixed with an air of general defeatism and negative values have predominated Capitalizing on remaining assets has been subordinate to managementt of persistent liabilities

Fortunately this has now been replaced by a dynamic approach to the problem which already has demonstrated its usefulness

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This Book

INJURIES

OF THE

SPINAL CORD

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